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Tesis Doctoral | Cecilia Arnaiz Schmitz

PROPUESTA METODOLÓGICA PARA LA PLANIFICACIÓN SOCIOECOLÓGICA DEL TERRITORIO

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Propuesta metodológica para una planificación socio-ecológica del territorio.
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Methodological proposal for a social-ecological land planning. Case studies along urban-rural gradients in Madrid Region.

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RESUMEN

Los cambios ambientales generalizados y profundos observados en el planeta a lo largo del último siglo, han puesto de relieve la necesidad urgente de conocer y cuantificar las influencias recíprocas entre los seres humanos y la naturaleza. Los cambios denunciados como ‘crisis ambiental’ desde los años 60 se perciben hoy como un acelerado y preocupante ‘Cambio Global’, que implica una modificación seria de la dinámica de las masas fluidas del Planeta (cambio climático) y una veloz transformación de las relaciones de las sociedades humanas entre sí y con el ambiente biofísico (cambio socioeconómico). Los cambios en los usos y coberturas del suelo (UCS) representan el mayor efecto primario o impulsor directo de los seres humanos sobre los sistemas naturales. Estos cambios generan procesos relevantes, tales como la fragmentación y pérdida de hábitats, principales amenazas para la conservación de la biodiversidad y la generación de los servicios de los ecosistemas (SEs). La propia desigualdad y la acentuación de la pobreza de muchas sociedades humanas -entre otros procesos ambientales bien documentados sobre desestabilización a escalas regionales y planetaria- se relacionan actualmente con estos cambios globales. Todo este complejo proceso explica, casi a cualquier escala, una estrecha relación perceptible entre casos que pueden ser interrelacionados con ayuda de modelos numéricos. Entre esos casos, uno muy notable se refiere al proceso de urbanización de un territorio dado, a las pautas de su crecimiento y al cambio en el tipo de economía, funcionamiento y función de los sistemas rurales o más o menos naturales donde estos fenómenos ocurren, como se trae a colación en la presente tesis doctoral.

Los fenómenos de la urbanización y del desarrollo socioeconómico, vinculados al uso y aprovechamiento de los recursos naturales, generan gran atención y preocupación, motivando el interés por comprender los gradientes urbano-rurales. La dualidad urbano-rural puede entenderse como un aumento del grado de influencia de los sistemas urbanos en los paisajes rurales, en los que las áreas urbanas juegan un papel importante en el contexto económico y en el flujo de SEs a la sociedad. El paradigma del gradiente urbano-rural es, por tanto, una poderosa herramienta para la investigación ecológica sobre las influencias urbanas en los ecosistemas y un marco apropiado para estudiar cuestiones socio-económicas relacionadas con la calidad y el nivel de vida. En la actualidad, existen sofisticadas herramientas metodológicas para cuantificar las interacciones entre la naturaleza y la sociedad. Sin embargo, hay poca consistencia en los métodos utilizados para formalizar, caracterizar y cuantificar los gradientes de urbanización, así como el grado de correspondencia o ‘acoplamiento’ entre las diferentes formas de habitar y utilizar el territorio y las estructuras del paisaje. La planificación de los usos del suelo es un elemento clave en la regulación territorial y puede ser una de las herramientas que garanticen un desarrollo

sostenible. Estos esquemas de planificación incluyen estrategias para controlar y regular el desarrollo urbano, principalmente a partir del establecimiento de los Espacios Naturales Protegidos (ENPs), pero su implementación causa conflictos entre los controles de planificación y desarrollo urbano o las demandas de la población rural, principalmente debido a las restricciones de acceso de los usuarios locales a los servicios de provisión. Se necesita, por tanto, un modelo de planificación integrada del territorio para gestionar la capacidad de los ecosistemas de suministrar servicios, así como la demanda, uso y disfrute de los mismos por parte de los beneficiarios, más allá de los límites administrativos (municipales, provinciales, autonómicos) que determinan y promueven la ruptura de estos gradientes socio-ecológicos.

El objetivo general de la tesis es elaborar líneas conceptuales y herramientas para el desarrollo de un nuevo modelo de planificación del territorio, basado en la integración de las estructuras socio-económica y de paisaje y en el suministro de SEs, capaz de superar los límites administrativos que plantea la planificación del territorio convencional. Para ello, se han desarrollado y aplicado procedimientos matemáticos, principalmente multivariantes, para identificar y cuantificar fenómenos propios de tramas socio-ecológicas. En líneas generales, los resultados obtenidos destacan la tendencia hacia el desacoplamiento socio-ecológico del territorio. Este proceso está relacionado con la pérdida de ruralidad y de las actividades económicas vinculadas a la base biofísica territorial, lo que ocasiona la alteración de sus tramas socio-ecológicas y del flujo de SEs. En este marco de referencia se revelan muchos factores cruciales para la gestión y planificación del territorio, como el papel de la conectividad socio-ecológica, el de los ENPs, o el bienestar de los habitantes de un municipio.

Los procesos esenciales detectados permiten sentar las bases para abordar una planificación socio-ecológica del territorio. Así, a partir de los resultados y conclusiones aportadas por los métodos cuantitativos aplicados en los diferentes estudios de esta tesis y con el objetivo de mitigar los procesos de desacoplamiento socio-ecológico detectados, se han elaborado las siguientes propuestas vinculadas a la planificación y gestión socio-ecológicas del territorio:

i) Aplicación de instrumentos políticos y económicos que favorezcan el mantenimiento de las actividades rurales tradicionales, especialmente en los ENPs y en sus áreas de influencia socioeconómica;

ii) Desarrollo de una red adecuada de infraestructuras que favorezca la conexión entre municipios vecinos y permita reforzar la cultura y la identidad local, evitando el alto grado de dependencia con la metrópolis;

iii) Generación de espacios de educación ambiental y de promoción del turismo cultural y de naturaleza basados en el valor del paisaje rural y de sus actividades económicas asociadas, que favorezcan al mantenimiento de este paisaje, la calidad de vida de las poblaciones locales y su desarrollo económico.

SUMMARY

The generalized and profound environmental changes observed in the planet over the last century have highlighted the urgent need to know and quantify the reciprocal influences between human beings and nature. The changes denounced as 'environmental crisis' since the 60s are today perceived as an accelerated and worrying 'Global Change', which implies a serious modification of the dynamics of the fluid masses of the planet (climate change) and a rapid transformation of the relation between human societies and with the biophysical environment (socio-economic change). Changes in land uses and land covers (LULC) represent the greatest primary direct driver of human beings on natural systems. These changes generate relevant processes, such as the fragmentation and loss of habitats, which are the main threats to the conservation of biodiversity and the generation of ecosystem services (ESs). The inequality and accentuation of poverty of many human societies, among other well-documented environmental processes on destabilization at regional and planetary scales, are currently related to these global changes. This complex process explains, almost at any scale, a close perceptible relationship between cases that can be interrelated with the help of numerical models. Among these cases, a highly notable one refers to the urbanization process of a given territory, to the patterns of its growth and to the change in the type of economy, functioning and function of the rural systems or more or less natural systems where these phenomena occur, as it is brought up in the present doctoral thesis.

The phenomena of urbanization and socioeconomic development, linked to the use and exploitation of natural resources, generate great attention and concern, motivating the interest to understand the urban-rural gradients. The urban-rural duality can be understood as an increase in the degree of influence of urban systems in rural landscapes, in which urban areas play an important role in the economic context and in the flow of SEs to society. The urban-rural gradient paradigm is, therefore, a powerful tool for ecological research on urban influences in ecosystems and an appropriate framework for studying socio-economic issues related to quality and standard of living. At present, there are sophisticated methodological tools to quantify the interactions between nature and society. However, there is little consistency in the methods used to

formalize, characterize and quantify urbanization gradients, as well as the degree of correspondence or 'coupling' between different ways to inhabit and use the territory and the landscape structures. Land use planning is a key element in territorial regulation and can be one of the tools that guarantee sustainable development. These planning schemes include strategies to control and regulate urban development, mainly through the establishment of Protected Areas (PAs), but their implementation causes conflicts between planning controls and urban development or the demands of the rural population, mainly due to access restrictions of local users to supply services. Therefore, an integrated land planning model is needed to manage the capacity of the ecosystems to supply services, as well as the demand, use and enjoyment of these by the beneficiaries, beyond the administrative limits (municipal, provincial, regional) that determine and promote the rupture of these social-ecological gradients.

The general objective of this thesis is to set conceptual lines and tools for the development of a new land planning model based on the integration of socio-economic and landscape structures and the ESs supply, capable of overcoming the administrative limits that the conventional land planning raises. In order to do this, mainly multivariate mathematical procedures have been developed and applied, to identify and quantify phenomena typical of social-ecological webs. In general, the results obtained highlight the trend towards the social-ecological decoupling of the territory. This process is related to the loss of rurality and the economic activities linked to the land biophysical base, which causes the alteration of its social-ecological webs and the flow of ESs. In this frame of reference, many crucial factors for the management and planning of the territory are revealed, such as the role of social-ecological connectivity, the role of the PAs, or the well-being of the inhabitants of a municipality.

The essential processes detected allow laying the foundations to tackle a social-ecological land planning. Thus, based on the results and conclusions provided by the quantitative methods applied in the different studies of this thesis and with the aim of mitigating the social-ecological decoupling processes detected, the following proposals related to land planning and social-ecological management have been prepared:

i) Implementation of political and economic instruments that favour the maintenance of traditional rural activities, especially in the PAs and in their socioeconomic influence areas;

ii) Development of an adequate infrastructure network that favours the connection between neighbouring municipalities and allows reinforcing the local culture and identity, avoiding the high degree of dependency on the metropolis;

iii) Generation of spaces for environmental education and promotion of cultural and nature-based tourism focused on the value of the rural landscape and its associated economic activities, which favour the maintenance of this landscape, the quality of life of local populations and their economic development.

1. Introducción

Los cambios ambientales generalizados y profundos observados en el planeta, especialmente a lo largo del último siglo, señalan la necesidad urgente de conocer mejor y cuantificar las influencias recíprocas entre los seres humanos y la naturaleza. 'Impulsores de cambios', tanto naturales como antropogénicos, transforman constantemente el medio, pudiéndose afirmar que no existen sistemas sociales sin naturaleza ni ecosistemas sin personas (Berkes & Folke, 1998; Petrosillo *et al*., 2015). La cumbre *Rio +20* de las Naciones Unidas, celebrada en Brasil en 2012, comprometió a numerosos gobiernos a crear un conjunto de Objetivos de Desarrollo Sostenible (ODS) que permitieran continuar con el impulso generado por los Objetivos de Desarrollo del Milenio (ODM) dentro de un marco global de desarrollo para más allá de 2015. Se acordó entonces que los ODS integraran las dimensiones 'social', 'económica' y 'ambiental' y proporcionaran orientación para que la humanidad prosperara a largo plazo.

Este marco de referencia permite gestionar los *trade-offs* o soluciones de compromiso entre los objetivos, maximizando sus sinergias e implementándolas desde escalas internacionales a escala de ciudad. La creciente evidencia y los cambios en el mundo real muestran de forma convincente que la humanidad está propiciando un 'Cambio Ambiental Global' y tal vez generando un nuevo periodo geológico denominado 'Antropoceno' (Griggs *et al.* 2013). La Conferencia de París sobre el Clima (COP-21; 2015) ha sido probablemente la más importante de las celebradas sobre el tema desde que, hace más de medio siglo, se diera la voz de alarma a cerca del 'Cambio Climático Antropogénico'. La importancia de esta conferencia se debe al reconocimiento de la información que ha llegado a acumularse apenas en las últimas dos décadas y al compromiso lógico de los gobiernos de casi todo el mundo sobre un cambio probablemente inevitable, pero que reclama medidas urgentes para mitigar sus efectos y, paralelamente, adaptar a él otra más reciente y rápida transformación: la socioeconómica –el 'Cambio Socioeconómico'-. Los cambios denunciados como 'crisis ambiental' desde los años 60 se perciben hoy como un acelerado y preocupante 'Cambio Global', que implica una modificación seria de la dinámica de las masas fluidas del Planeta (cambio climático) y una veloz transformación de las relaciones de las sociedades humanas entre sí y con el ambiente biofísico (cambio socioeconómico) (Pineda *et al*., 2018). El marco actual del debate internacional sobre las relaciones entre naturaleza y sociedad podría centrarse, pues, en los citados conceptos de Antropoceno y Cambio Global.

El informe ‘Evaluación de los Ecosistemas del Milenio’ (MEA, 2005), señalaba que, apenas en los últimos 50 años, la humanidad ha transformado los ecosistemas más rápida y extensamente que en ningún otro período comparable de su historia (Diaz-Pineda, 1984). Los cambios en los usos y coberturas del suelo (UCS) representan quizá el mayor efecto primario o ‘impulsor directo’ de las sociedades humanas sobre los sistemas naturales (MEA, 2005; Arnaiz-Schmitz *et al*., 2018*a*). Estos cambios generan, de hecho, procesos con incidencias ambientales muy relevantes, como la erosión del suelo, cambios de infiltración hídrica y escorrentía de cuencas hidrográficas con efectos de colmatación de humedales y otros fenómenos combinados (González-Bernáldez, 1981; Turner *et al*., 1990; Pineda & Schmitz, 2011, entre otros). La denominada ‘fragmentación de hábitats’, percibida sobre todo con perspectivas zoológicas, y la desaparición de todo tipo de biotopos representan serias amenazas para la conservación de la biodiversidad. Se conocen bien los diferentes cambios generados por las actividades culturales en el funcionamiento y consiguiente función de los ecosistemas. Estos cambios se remontan obviamente a culturas recolectoras, cinegéticas y agrícolas ancestrales, pero en el último siglo la intensidad y extensión de la cultura han aumentado enormemente.

La citada función de los ecosistemas ha sido percibida, inicialmente por economistas, como la generación de ‘servicios de los ecosistemas’ (SEs) a las sociedades humanas (Gutman, 2007) y los cambios en tales servicios han pasado a ser recientemente objeto de estudios, descriptivos o experimentales, en casi todo el mundo (Corbera *et al.,* 2007; Gutman, 2007; Fisher *et al.,* 2008; Martín-López & Montes, 2011; Montes *et al,* 2013, entre otros). La propia desigualdad y acentuación de la pobreza de muchas sociedades humanas -entre otros procesos ambientales bien documentados sobre desestabilización a escalas regionales y planetaria- se relacionan actualmente con estos cambios globales (Turner *et al*., 1990; Steffen *et al.* 2015). Todo este complejo proceso explica, casi a cualquier escala, una estrecha relación perceptible entre casos que pueden ser interrelacionados con ayuda de modelos numéricos. Entre esos casos, uno de percepción muy evidente se refiere al proceso de urbanización de un territorio dado, a las pautas de su crecimiento y al cambio en el tipo de economía, funcionamiento y función de los sistemas rurales o más o menos naturales donde estos fenómenos ocurren, como se trae a colación en la presente tesis doctoral.

Los fenómenos de urbanización y desarrollo socioeconómico, vinculados al uso y aprovechamiento de los recursos naturales, vienen generando, en efecto, un gran interés y preocupación en diferentes foros. Es un hecho que los conflictos entre crecimiento y ambiente surgen en cuanto se percibe que el sistema natural es finito. La definición formal de *economía* describe a esta área de conocimiento como una "ciencia que explica y predice el comportamiento del ser humano en lo referente a procesos de elección derivados de la existencia de recursos limitados para hacer frente a necesidades ilimitadas". Unos recursos limitados determinan la concepción de casi cualquier sistema de uso humano como un 'modelo circular entre economía y medio natural'. Thomas R. Malthus (1766-1834), uno de los primeros economistas preocupados por la escasez de recursos naturales, planteaba en su libro 'Ensayo sobre el principio de la población' la existencia de límites naturales de espacio y alimentos. En 1846, este autor afirma que "mientras que la población crece de manera geométrica, los medios de subsistencia lo hacen de manera aritmética". Esto daría lugar a un crecimiento de la población regulado, según Malthus, de manera natural, ya que la escasez de recursos marcaría el fin de tal crecimiento demográfico. En la actualidad es posible afirmar que Malthus se equivocaba. Por un lado, él no podía considerar que los avances tecnológicos permitirían, de hecho, que las tasas de crecimiento alimentario superaran a las demográficas y, por otro, debía desconocer la idea de 'sostenibilidad', planteada ya en 1713 por Hans C. von Carlovitz (1645-1714). Desde luego tampoco debía conocer la idea de 'tasa de renovación' (*turnover rate*) contenida, de hecho, en las observaciones de von Carlovitz y luego asociada al desarrollo de un área de conocimiento que se denominaría *ecología* (ver Diaz-Pineda, 2018).

El deterioro ambiental, que conlleva la explotación de los recursos naturales mediante una tecnología cada vez más eficaz, es sin embargo un hecho cada vez más latente en la sociedad contemporánea. Así, desde principios de 1960 se toma conciencia de la gravedad de determinados problemas ambientales percibidos a diferentes escalas dentro y fuera de algunos países de la OCDE. La Asamblea General de las Naciones Unidas aprobó en 1982 la 'Carta Mundial de la Tierra' y creó en 1983 la Comisión Mundial del Medio Ambiente y del Desarrollo. Esta comisión, tras celebrar numerosos encuentros participativos por todo el mundo, presentó en su Asamblea General de 1987 el Informe 'Nuestro Futuro Común', más conocido como 'Informe Brundtland' (Bermejo, 2014). En este informe se formalizó el concepto de desarrollo sostenible: "El desarrollo que satisface las necesidades de la generación presente sin comprometer la capacidad de las generaciones futuras para satisfacer sus propias necesidades". La Cumbre de la Tierra de Río (1992) sentó las bases para lograr este modelo de desarrollo.

El concepto de Desarrollo Sostenible ha sido tildado por algunos autores como poco preciso o incluso antagónico y ha provocado conflictos entre expertos en cuanto a su interpretación, significado y uso. Para los economistas neoclásicos el concepto de 'crecimiento' está asociado a un aumento cuantitativo de la producción y el de 'desarrollo' a un aumento cualitativo de ésta. Es aquí donde aparece una brecha entre 'desarrollo económico' y 'sostenibilidad', y es una realidad que el sistema económico monetariza la producción de cualquier país midiéndola a través de descriptores considerados como 'indicadores' (como el producto interior bruto, PIB). Éstos excluyen sistemáticamente los procesos biológicos y naturales que curiosamente permiten esa producción. Esto aumenta las diferencias entre medio natural y economía, dándose la paradoja de que, en lugar de ampliar realmente el campo de lo económico más allá de lo monetario, se reduce también el campo de lo ambiental a lo puramente crematístico bajo una lógica maximizadora y monetarista (Lomas *et al.*, 2007). Ante este panorama político, social y económico, autores como Daly (1996) o Costanza (1992) proponen la alternativa del 'crecimiento cero' a manera de símil del 'crecimiento sostenible'. La idea que motiva su propuesta es la de que las tasas de crecimiento se anulen con la de renovación de recursos. Para lograrlo, la cantidad de habitantes y su capacidad de consumo deben limitarse, la velocidad de explotación del medio debe ser igual a la regeneración de los recursos naturales (su *turnover*), la cantidad de desechos (por ejemplo, emisiones) debe corresponder con la capacidad de asimilación del medio y la explotación de recursos naturales debe corresponder a las tasas de extracción de sustitutivos renovables (una forma de gestión del *turnover*), debiéndose tener en cuenta la 'resiliencia' del medio (Holling, 1973; Leal, 2008) –en realidad una propiedad asociada al *turnover*-. Sin embargo, este planteamiento es refutable pues, este tipo de crecimiento o no crecimiento, propone conjuntos de 'soluciones no Pareto óptimas', es decir, situaciones en las que ningún agente puede mejorar sin que otro empeore. Surge aquí el paradigma de la sostenibilidad, que genera una brecha muy marcada entre varias corrientes de pensamiento (dos corrientes, según Naredo, 1996): surgen economistas que basan sus investigaciones en líneas de pensamiento aparentemente opuestas, pero con claves comunes: una 'sostenibilidad débil' (formulada desde la racionalidad propia de la economía estándar) y otra 'sostenibilidad fuerte' (formulada desde la racionalidad de una economía de la física, que es la termodinámica, y de una economía de la naturaleza, que es la ecología) (Tabla 1).

Por un lado, los economistas ambientales se basan en criterios de la economía neoclásica y siguen la corriente de pensamiento trazada por Solow (1992), apoyando la hipótesis de que el crecimiento será sostenible si el capital agregado no disminuye a lo largo del tiempo. Afirman que es imposible dejar el planeta a las futuras generaciones en un estado estático, en la misma forma en la que lo hubiéramos encontrado. Estos economistas abogan por un uso de los factores de producción (tierra, trabajo, capital) intercambiable. Es decir, los agentes económicos intercambian con los futuros agentes económicos de recursos naturales a cambio de capacidades de producción más sofisticadas. Está línea de pensamiento está sujeta a una serie de condiciones necesarias para su cumplimiento. Entre ellas la más significativa es que se da por hecho la capacidad del desarrollo científico y tecnológico de solventar la escasez de recursos además de que las generaciones futuras tendrán que acomodarse al escenario construido por las presentes, o la necesaria reinversión de las rentas generadas por los recursos naturales en el capital técnico encargado de sustituirlo. Según Solow (1992), “El compromiso de la sostenibilidad se concreta en el compromiso de mantener un determinado montante de inversión productiva”. El objetivo claro de esta economía de mercado puede resumirse en “el estudio de los recursos escasos para propósitos alternativos presentes y futuros por medio del sistema de precios” (Robbins & Villegas 1980).

Por otro lado, como crítica a la primera corriente de pensamiento, aparece el término ‘economía ecológica’ que defiende la idea de una sostenibilidad fuerte. En este caso, sus estudiosos aseguran que el progreso tecnológico es incierto y que no es posible la sustitución entre los diferentes componentes del capital agregado. Además, se oponen a la idea de que las externalidades ambientales se internalizan el sistema de precios -para ellos, la preservación del *stock* de capital natural es una premisa indispensable para el desarrollo sostenible-. La principal limitación que estos autores advierten en la interpretación que se hace de la sostenibilidad, desde la noción usual de sistema económico, proviene de la consideración de que los objetos que componen esa versión ampliada del *stock* de capital no son ni homogéneos ni necesariamente sustituibles. Es más, se postula que los elementos y sistemas que componen el ‘capital natural’ se caracterizan más bien por ser complementarios que sustitutivos con respecto al capital producido por el ser humano (Daly, 1990; Naredo, 1996).

Tabla 1. Análisis comparativo entre las corrientes de pensamiento sobre sostenibilidad. (modificada de Figueroa, 2004).

ECONOMÍA AMBIENTAL (Sostenibilidad débil)	**ECONOMÍA ECOLÓGICA (Sostenibilidad fuerte)**
• Concepto mecanicista • Compatibilidad entre sostenibilidad y crecimiento • Capital natural sustituible por capital humano (capital agregado) • Optimismo tecnológico • Monetarista • La capacidad de producir utilidad no disminuye a lo largo del tiempo • No respeta los límites biofísicos	• Concepto ecológico • Incompatibilidad entre sostenibilidad y crecimiento • Capital natural complementario al capital humano • Escepticismo tecnológico • Recursos no cuantificables monetariamente • Preservación de stock de capital natural

A pesar de las notables diferencias entre las economías ambiental y ecológica, ambas corrientes de pensamiento tienen en común el campo de la política ambiental, la vía administrativa y el campo institucional (Naredo 1999). Sin embargo, continúa existiendo una fuerte incomunicación entre ambos puntos de vista y, en consecuencia, autores como Costanza (1992) o Azqueta (1992) insisten en la importancia de la coordinación de los planteamientos de ambas líneas de investigación.

En 2012, la Conferencia *Río +20* tuvo entre sus objetivos operar de alguna forma en una transición hacia 'economías más verdes'. En el marco de esta cumbre, el Programa de las Naciones Unidas para el Medio Ambiente (PNUMA) ya elaboró el documento 'Hacia una economía verde: vías para el desarrollo sostenible y la erradicación de la pobreza*'* (PNUMA, 2011). Este informe define la 'economía verde' como "aquella que conduce a una mejora del bienestar humano y la equidad social a la vez que reduce significativamente los riesgos ambientales y la escasez ecológica" (PNUMA, 2011; Gómez-Baggethun, 2012). El concepto de 'economía verde' está estrechamente relacionado con el de 'economía ecológica', pero, a diferencia de éste, su enfoque parece más político que teórico (Kahle & Gurel-Atay, 2014): es la economía que persigue un desarrollo con bajas emisiones de carbono, eficaz uso de los recursos y socialmente inclusiva (Morganti, 2015). Para ello se requiere una acción humana colectiva, lo que implica la administración de toda la Ecosfera -el ecosistema planetario-, que incluyera acciones tales como la 'descarbonización' de la economía global, la mejora de los sumideros de carbono de la biosfera, cambios de comportamiento, determinadas innovaciones tecnológicas, nuevos acuerdos de gobernanza y valores sociales transformados (Steffen *et al.,* 2018). En la actualidad, quizá por su mayor sencillez de entendimiento y aplicación, dominan las propuestas de la economía ambiental frente a las de la economía ecológica. Ésta, además, implica cambios en modelos de gestión establecidos a diferentes niveles (Álvarez *et al.,* 2006; Naredo, 2003) y pretende desarrollar un enfoque 'ecointegrador' -que supone manejar información física (abiótica), biológica y socioeconómica siempre en términos de sistema (en realidad el concepto actual de ecosistema; Díaz-Pineda, 2018) para gestionar sistemas económicos "teniendo en cuenta su compatibilidad con los ecosistemas con los que están relacionados".

Las complejas interacciones entre ecosistemas y decisiones de desarrollo de la sociedad humana y cómo las consecuencias de estas decisiones influyen en el bienestar y en los valores humanos, constituyen hoy una importante área de investigación. Por el momento pueden observarse aquí algunas lagunas conceptuales, análisis de datos reales (cada vez mejores y de más fácil acceso) y modelos matemáticos en los que basar predicciones bien fundamentadas, obtener conclusiones y descartar opiniones subjetivas emitidas con excesiva frecuencia. Por ello, es esencial trabajar en la compleja interfase entre los sistemas ecológicos y los sociales –si una separación nítida entre ellos es realmente posible-, en la que se desarrollan las políticas y acciones de planificación y gestión de los recursos naturales. Esta tarea implica obviamente integrar las ciencias sociales y naturales para abordar los actuales desafíos ambientales con perspectiva de sostenibilidad.

Por su parte, el concepto de 'sistema socio-ecológico' o 'socio-ecosistema' (SSE) surgió al reconocerse la estrecha interacción existente entre sociedad, en términos de sistema socioeconómico, y sistemas naturales (ver Daly, 1990, 1996, 1997). La formalización teórica de este concepto ha desencadenado una línea de investigación y una literatura científica, unas veces descriptiva o narrativa y otras con base numérica o experimental, en torno a los SSEs (Berkes & Folke 1998, Levin 1998, Berkes *et al*., 2003, Anderies *et al*., 2004, Ostrom, 2009, entre otros). Viene a considerarse que los SSEs son 'sistemas co-evolutivos' de acuerdo con circunstancias tales como que las estructuras territoriales y socioeconómicas mantienen realmente interacciones recíprocas, como las estudiadas por De Aranzabal *et al*. (2008). La co-evolución biofísico-cultural donde debió surgir la agricultura sería un ejemplo de esto (Vavilov, 1951). Los SSEs, como sistemas adaptativos complejos, tendrían propiedades emergentes (Holland, 1995; Levin *et al*., 2013). Entre estas propiedades, susceptibles de identificación y análisis, se encuentran las dependientes de variables sociales y ecológicas consideradas al analizar el sistema, su escala y los métodos utilizados para estudiar sus interacciones (Herrero-Jáuregui *et al*., 2018*a*). Los procesos culturales y ecológicos operan, sin embargo, a diferentes escalas espaciales y temporales, así que puede ser difícil encontrar métodos apropiados para medir y combinar ambos tipos de variables, considerando además que el resultado de estas interacciones resulta clave para proveer a la sociedad humana de los SEs, anteriormente mencionados, que resulten esenciales para ella (Reyers *et al*., 2013).

El abandono y la transformación de los UCS ha provocado la disminución de SEs relacionados con la regulación de procesos ecológicos, por ejemplo, el ciclo del agua, y culturales, como la identidad local, el conocimiento ecológico tradicional (CET) o el enriquecimiento espiritual (Slemp *et al*., 2012). Además, estas formas de gestión o administración de los UCS, ligadas principalmente a la intensificación agraria y a la urbanización, provocan cambios serios en las interacciones socio-ecológicas (Lambin *et al*., 2001; Plieninger *et a*l., 2016; Rasmussen, 2018). La expansión urbana se considera en todo el mundo como uno de los principales impulsores directos de los UCS y pérdida de hábitats y la forma más dramática de pérdida de diversidad biológica, SEs y los vínculos de todos ellos con el bienestar social (Luck & Wu, 2002; Foley *et al*., 2005; Díaz *et al*., 2006; Fisher & Turner, 2008; Seto *et al*., 2012; Wu, 2013; Newbold *et al*., 2015). Los diferentes procesos de urbanización no solo transforman paisajes rurales o naturales en sistemas urbanos, sino que modifican también complejas relaciones socio-ecológicas a través de cambios demográficos y económicos, así como los estilos de vida asociados (Antrop, 2004; Seto *et al*., 2010).

En las últimas décadas, la expansión urbana progresiva, relacionada con el aumento del tamaño de las ciudades y el abandono rural (Vos & Klijn, 2000; Antrop, 2005, 2006), ha despertado el interés por comprender los gradientes urbano-rurales (McDonnell *et al*., 1993, 1997, Haase & Nuissl, 2010, entre otros). La dualidad urbano-rural puede entenderse como un aumento del grado de influencia de los sistemas urbanos en los paisajes rurales, en los que las áreas urbanas juegan un papel importante en el contexto económico y en el flujo de SEs a la sociedad (McMichael *et al.,* 2003; Modica *et al.,* 2012).

La transformación gradual de los sistemas rurales genera 'desacoplamientos' socio-ecológicos (i.e. sistemas en los que las interacciones ser humano-ambiente están desajustadas) que dan lugar a sistemas de transición urbano-rural a través de un complejo proceso de periurbanización que, en la mayoría de los casos, dificulta la identificación del límite entre la ciudad y el campo (Arnaiz-Schmitz *et al*., 2018*a*). Este proceso genera áreas de transición donde las actividades urbanas y rurales se yuxtaponen y el paisaje se somete a modificaciones rápidas inducidas por el ser humano (Antrop, 2000). El paradigma del gradiente urbano-rural constituye así una interesante perspectiva para la investigación ecológica sobre las influencias urbanas en los ecosistemas (McDonnell *et al.,* 1997; Metzger *et al*., 2010; Vizzari & Sigura, 2015; Salvati *et al*., 2017) y un marco apropiado para estudiar cuestiones socio-económicas relacionadas con la calidad y el nivel de vida (Savitch, 2003; Berry & Okulicz-Kozaryn, 2011; Gómez-Baggethun & Barton, 2013). La presente tesis está centrada básicamente en esta idea.

El suministro de SEs depende en gran medida de las funciones de los sistemas rurales y urbanos. En este sentido, los esquemas de planificación ambiental incluyen estrategias para controlar y regular el desarrollo urbano, principalmente a partir del establecimiento de Espacios Naturales Protegidos (ENPs), especialmente diseñados para preservar la biodiversidad y los flujos ecológicos (Martín López & Montes, 2015). Es, no obstante, ampliamente conocido que hasta hace poco y debido a la transformación acelerada de paisajes naturales y rurales, el concepto de 'naturalidad' ha sido el principio rector de los objetivos de conservación de la naturaleza y la toma de decisiones (Hobbs *et al*., 2010; Cole & Yung, 2012). Generalmente estos esquemas de conservación han sido implementados a través de redes de reservas naturales con leyes, políticas o formas de gestión que han causado muchos conflictos entre los controles de planificación y desarrollo urbano o las demandas de la población rural, principalmente debido a las restricciones de acceso de los usuarios locales a los servicios de provisión (Gutman, 2007; Martín-López *et al*., 2011; Schmitz *et al*., 2012). Esto a menudo ha causado el abandono rural, procesos de matorralización y pérdida de SEs asociados a los paisajes culturales, como los sistemas tradicionales de dehesa característicos de la Península Ibérica (Plieninger, 2006; Schmitz *et al*., 2012, 2017, entre otros). Además, varios estudios destacan un importante proceso de expansión urbana en torno a los ENPs, lo que sugiere que su establecimiento y gestión no son efectivos para frenar el desarrollo de los asentamientos humanos en sus tierras circundantes (Trzyna, 2007; Arnaiz-Schmitz *et al*., 2018*a*). El cambio de las prioridades de gestión de los ENPs está necesariamente vinculado a los enfoques socio-ecológicos relacionados con la oferta-demanda de SEs (Corbera *et al.,* 2007; Gutman, 2007).

En la actualidad hay métodos más o menos sofisticados para cuantificar las interacciones entre la naturaleza y la sociedad en territorios concretos (Salvati & Zitti, 2009; Salvati & Serra, 2016; Schmitz *et al*., 2003, 2012, 2018). Sin embargo, hay poca consistencia en los métodos utilizados para formalizar, caracterizar y cuantificar gradientes en torno a procesos de urbanización (Raciti *et al.,* 2012; Gianotti *et al.,* 2016), así como el grado de correspondencia o 'acoplamiento' entre las diferentes formas de habitar y utilizar el territorio y las estructuras del paisaje. La presente tesis analiza también el suministro-demanda de SEs evaluando este grado de acoplamiento y desacoplamiento entre componentes ecológicos y socioeconómicos a lo largo de gradientes rural-urbanos por efecto del planeamiento territorial vigente, tratándose de implementar nuevos procedimientos que ayuden a la planificación territorial y que vayan más allá de los límites administrativos municipales y supramunicipales.

2. Justificación: marco conceptual

Esta tesis doctoral se enmarca dentro del campo emergente de las 'ciencias de la sostenibilidad' (Kates, 2011), basado en la necesidad de contar con una 'ciencia con conciencia social' que dirija su investigación teórica a la resolución de problemas complejos de la interfase naturaleza-sociedad. En este marco se contemplan análisis de SSEs y se desarrollan procedimientos innovadores para aplicar en el territorio un planeamiento con base socio-ecológica. Los UCS proporcionan información sobre la evolución de las características ecológicas del territorio y la modificación de sus valores naturales y culturales. Asimismo, sirven de referencia determinados estudios previos de evaluación de impacto ambiental, restauración y planificación (Gómez-Orea, Díaz-Pineda *et al*., 1975; Zárate *et al*., 1998; Tress & Tress, 2003; García-Frapolli *et al*., 2007; Prieto *et al*., 2008; Koomen *et al*., 2011).

La tesis surge en el contexto planteado por el Proyecto de I+D (Ministerio de Economía y Competitividad): 'Evaluación de los flujos de servicios de los ecosistemas en gradientes rural-urbanos: aplicabilidad a la planificación socio-ecológica del territorio (Ecogradientes)'; CGL2014-53782-P. Su hipótesis de partida es que los Planes Generales Municipales de Ordenación Urbana (PGOM) vigentes, y los planes de escala subregional como los Planes Rectores de Uso y Gestión (PRUG) de los ENs, fomentan la dicotomía urbano-rural, ignorando las tramas socio-ecológicas patentes en gradientes espacio-temporales.

Para abordar la complejidad de las interacciones entre naturaleza y sociedad en sistemas rurales y urbanos, se utiliza el marco conceptual antes definido sobre los SSEs, cuya idea permite modelizar los gradientes urbano-rurales objeto de estudio, donde, a diferentes escalas, se suministran a la sociedad SEs mediando un sistema de gobernanza (Fig. 1).

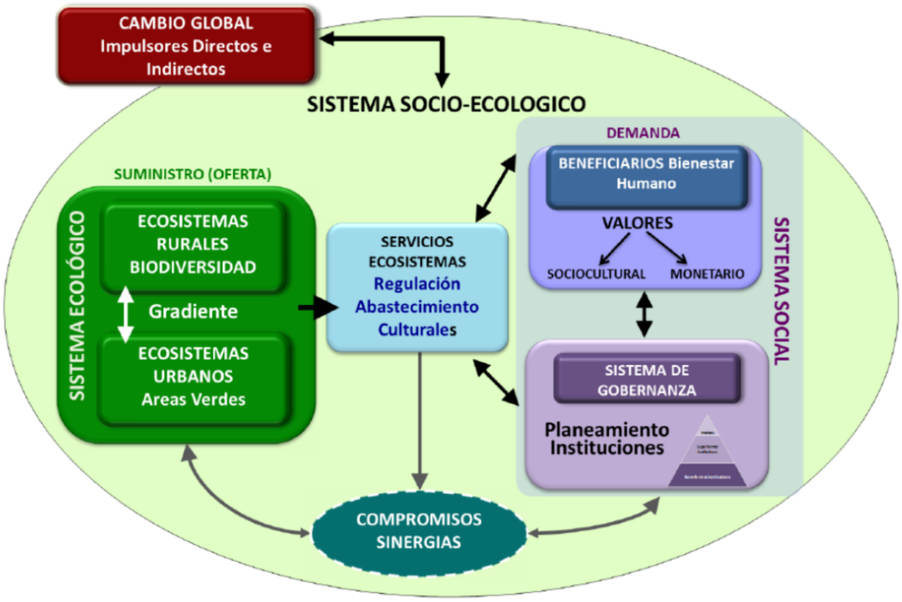

Figura 1. Marco conceptual de los SEs establecido en el proyecto I+D *Ecogradientes*. El límite trazado entre el sistema ecológico (incluyendo los ecosistemas urbanos) y el social (sociedad beneficiaria) es arbitrario. Ambos sistemas se han considerado vinculados por flujos de oferta-demanda de SEs gestionados por 'procesos de gobernanza' que incluyen el planeamiento territorial. El análisis y la cartografía de los compromisos y sinergias, resultado de la interacción entre los diferentes componentes del sistema, constituyen objetivos clave para la gestión de los gradientes urbano-rurales.

La planificación territorial juega un papel fundamental en la evolución de los usos del suelo: las bases en que se asienta y se legisla guardan relación directa con éstos. Por ello la planificación de los usos del suelo es un componente clave en la regulación territorial y es una de las herramientas que garantizan un desarrollo sostenible. Se necesita, pues, un modelo de planificación integrada del territorio para gestionar el suministro de servicios de los ecosistemas, así como la demanda, uso y disfrute de éstos por los beneficiarios, más allá de los límites administrativos (municipales, provinciales, autonómicos, áreas protegidas) que, de hecho, determinan la ruptura de estos gradientes socio-ecológicos. La presente tesis analiza el suministro-demanda de SEs evaluando el acoplamiento o desacoplamiento entre componentes y procesos ecológicos y socioeconómicos. Esto se hace a lo largo de gradientes rural-urbanos.

3. Área de estudio: Comunidad de Madrid

La tesis acota su principal área de estudio en la Comunidad de Madrid y aprovecha sus peculiares características socio-ecológicas como laboratorio experimental de nuevas herramientas de utilidad para la gestión extrapolables a otros territorios y premisas.

La Comunidad Autónoma de Madrid se configuró en 1982, mediante autorización legislativa (Ley Orgánica 6/1982, de 7 de julio, donde "se autoriza a la provincia de Madrid, por razones de interés nacional, para constituirse en Comunidad Autónoma") y posterior Estatuto de Autonomía de 1 de marzo de 1983 (Ley Orgánica 3/1983, del 25 de febrero). El territorio de la Comunidad de Madrid alcanzó sus límites territoriales actuales en 1833 con la división de España en provincias, una de las cuales fue la de Madrid. En esta división, la provincia fue adscrita a la región de Castilla la Nueva, junto con Ciudad Real, Cuenca, Guadalajara y Toledo. La actual región de Madrid limita con las provincias castellano-leonesas de Ávila y Segovia y las provincias castellano-manchegas de Guadalajara, Cuenca y Toledo. Territorialmente se organiza en 179 municipios (Fig. 2). Tiene una extensión de 8.027 km^2 (el 1,59% de la superficie de España).

En los sucesivos capítulos que contiene esta tesis se estudia esta región y sus gradientes urbano-rurales a diferentes escalas. En la actualidad este territorio está considerado como uno de los *hotspots* europeos en desarrollo urbano (Comisión Europea, 2006; Kuemmerle *et al.,* 2016). En este área la altitud constituye el factor ecológico principal (De Miguel & Díaz Pineda, 1999; Schmitz *et al.,* 2007); varía desde 400 m snm en los valles a más de 2000 m en sus cumbres montañosas. Un tercio de la zona, al N y al W, está ocupado por montañas silíceas cuyos usos del suelo son principalmente silvo-pastorales tradicionales. Este sector presenta un gradiente altitudinal bien marcado, sucesivamente con bosques de encina, roble, pino y pastos de alta montaña mediterránea. El área del centro y E de la región es la cuenca sedimentaria del río Tajo, que origina paisajes eminentemente agrícolas y agropecuarios. A lo largo de todo este gradiente hay una clara variación de los UCS, incluyéndose poblaciones dispersas por todo el territorio y la aglomeración metropolitana central, dando lugar todos estos usos a diferentes tipos de paisaje.

Este territorio se ha utilizado secularmente para diferentes actividades humanas como los sistemas rurales mixtos tradicionales basados en la agricultura, la silvicultura y el pastoreo (Schmitz *et al.,* 2007; Schmitz *et al.,* 2017). Hasta el proceso de industrialización en 1950, los límites entre la ciudad de Madrid y el campo parecían bastante bien definidos. En las últimas décadas, esta región, como otros paisajes culturales europeos, se ha transformado a través de un proceso bidireccional de intensificación del uso de la tierra y de abandono rural (Kuemmerle *et al.,* 2016; Schmitz *et al.,* 2017), causando modificaciones importantes de una antigua dicotomía urbano-rural (Stellmes *et al.,* 2013). El crecimiento urbano de Madrid corresponde principalmente a patrones de expansión urbana. Es un caso particularmente paradigmático en España, dada su importancia, tamaño y desarrollo reciente (Morollón *et al.,* 2016). Junto a la pérdida de ruralidad, diferentes impulsores socioeconómicos han promovido una intensa descentralización, implicando la redistribución de la población y el empleo, tasas muy altas de crecimiento de la vivienda y emergencia de nuevos asentamientos humanos con importantes consecuencias en las características culturales y socioeconómicas (Comisión Europea, 2006). Un factor clave en la descentralización ha sido la movilidad urbana, basada en el desarrollo de una red de infraestructura de transporte metropolitana (Hewitt & Hernández-Jiménez, 2010; Díaz-Pacheco & García-Palomares, 2014).

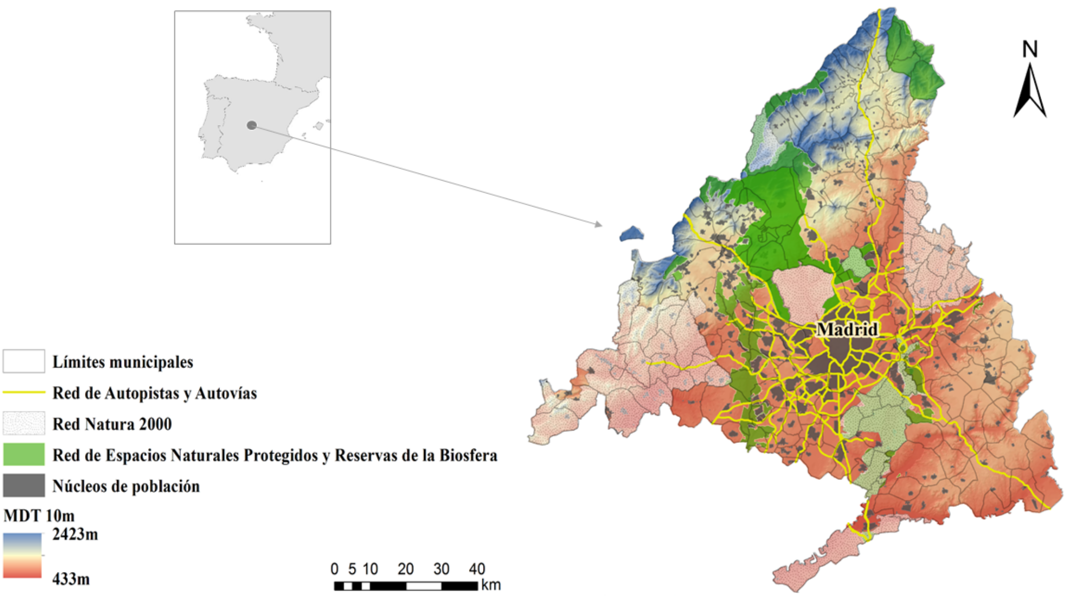

Figura 2. Área de estudio. Mapa de la Comunidad de Madrid ilustrando la Red de Espacios Naturales Protegidos (Parques Regionales, Parque Nacional y Reservas de la Biosfera). Red Natura 2000. Núcleos de población, y red principal de transporte por carretera.

El territorio de Madrid ofrece un espacio de estudio excelente donde desarrollar métodos de base matemática, ecológica y socioeconómica que sirven para diseñar una nueva planificación territorial. Hace cuatro décadas que fue aprobado el ‘Plan Especial de Protección del Medio Físico de la Provincia de Madrid’ (Gómez-Orea, Díaz-Pineda *et al.,* 1975). Fue el primer informe vinculante de planificación ambiental emitido por la Administración española. Se elaboró a través de una comisión de expertos, ‘COPLACO’, creada con ese propósito. El fundamento del informe radicaba en considerar los diferentes tipos de ecosistemas reconocidos en este territorio como ‘estructuras de acogida del planeamiento’ entonces previsto con el horizonte del año 2000. Se trataba de un estudio ecológico aplicado de forma novedosa siguiendo directrices propias de las escuelas de arquitectura del paisaje de I. McHarg y R. Forman, en Estados Unidos, y de ecología continental de F. González-Bernáldez, en España. Sus estudios e iniciativas de base científica intercambiaban experiencias con otras escuelas y perspectivas, mediando el ‘Instituto Batelle-Columbus’ de Ohio, el ‘London Green Belt Council’ de Inglaterra y el ‘CSIRO’ australiano.

En la actualidad el planeamiento territorial ha sufrido cambios de perspectiva, percepción y gestión ambiental y sustituciones importantes de valores derivadas del crecimiento demográfico, diferentes circunstancias ambientales y organización sociopolítica. Hoy puede pensarse en una planificación en Madrid a diferentes escalas. Se han desarrollado nuevos métodos que permiten comparar estructuras, así como líneas conceptuales y herramientas para nuevos modelos de planificación basada en el reconocimiento de ‘servicios de los ecosistemas’ que pueden ser evaluados disponiéndose esos métodos y, en cierta medida, pueden superarse los límites de una planificación territorial que no ha dispuesto aún de estos modelos de análisis y predicción. En la Región de Madrid se reconoce ahora una compleja matriz territorial que puede derivar por diferentes vías, mediando una ‘dicotomía urbano-rural’ donde persisten áreas con altos valores naturales y culturales reconocidos (regional, nacional e internacionalmente) y una tendencia de cambio debida a un desarrollo económico de varias dimensiones y un crecimiento urbano formidable.

Este área se ha considerado, pues, como material de estudio en la presente tesis. Se trata de un territorio que comprende hoy una red de ENPs que ocupan 120.964,46 ha -Madrid es la segunda provincia española con mayor superficie oficialmente protegida a diferentes niveles de la Administración Ambiental, después de Valencia (EUROPARC, 2017)-. Contiene: *i)* tres Parques Regionales (‘Parque Regional de la Cuenca Alta del Río Manzanares‘, creado en 1985, ’Parque Regional del Sudeste‘, creado en 1994 y ’Parque Regional del Curso Medio del Río Guadarrama‘, creado en 1999 -una figura de protección declarada por el Gobierno Regional de Madrid similar a la categoría de gestión de PAs de la Unión Internacional para la Conservación de la Naturaleza (UICN) VI (IUCN 1994)-; *ii)* un Parque Nacional, creado en 2013 (‘Parque Nacional de la Sierra de Guadarrama‘), declarado de interés general por el Gobierno de España debido a sus sistemas naturales bien conservados; *iii)* dos Reservas de la Biosfera, creadas en 2005 (‘Cuenca Alta del Río Manzanares‘ y ‘Sierra del Rincón‘) diseñada por el Programa Hombre y la Biosfera (MaB) de la UNESCO, representando la integración de la diversidad cultural y biológica, especialmente el papel del CET en la gestión de ecosistemas; y *iv)* siete sitios seleccionados bajo la red Natura 2000 (áreas especiales de conservación para aves, ZEPA, y lugares de interés comunitario, LIC).

4. Objetivo general

El objetivo general de esta tesis es elaborar líneas conceptuales y herramientas para el desarrollo de un nuevo modelo de planificación del territorio basado en la integración de las estructuras socio-económica y de paisaje y en el suministro de SEs. Se trata de una tarea capaz de superar los límites administrativos que plantea la planificación territorial hasta ahora convencional. Para ello se han desarrollado y aplicado procedimientos matemáticos, principalmente multivariantes, que permiten identificar y cuantificar fenómenos propios de tramas socio-ecológicas. Como resultado de los procesos esenciales que sean detectados puede abordarse una planificación socio-ecológica del territorio.

4.1. Objetivos específicos

a. Analizar la evolución del concepto de 'sistema socio-ecológico' y sus implicaciones ante una línea de investigación ya abierta para la tesis dentro de este marco de referencia.
b. Aplicar procedimientos para integrar datos sociales y ecológicos que permitan analizar la 'conectividad socio-ecológica' y su relación con el grado de 'naturalidad' del territorio.
c. Desarrollar un modelo numérico para cuantificar y tipificar el 'grado de acoplamiento o desacoplamiento socio-ecológico' y generar 'escenarios de cambio' en diferentes casos de estudio.
d. Cuantificar la eficacia de la declaración y consiguiente gestión de ENPs en lo relativo a procesos de acoplamiento socio-ecológico y mantenimiento de los SEs.
e. Valorar los paisajes rurales, analizar su percepción por los visitantes y la consiguiente incidencia del turismo en el mundo rural y la eficacia de la gestión de los ENPs a este respecto.

Estos objetivos permiten desarrollar herramientas innovadoras aplicables a un modelo planificación socio-ecológica del espacio rural-urbano.

5. Resultados

Los resultados obtenidos responden a los métodos cuantitativos empleados para alcanzar objetivos mencionados. Estos métodos, objetivos y resultados han generado ocho artículos de investigación, siete de ellos publicados o aceptados en revistas científicas de reconocido prestigio y un capítulo de libro publicado por una editorial de relevancia internacional.

Objetivo a

Para alcanzar este objetivo se exploró el uso del término 'sistema socio-ecológico' (SSE), analizándose si éste corresponde apenas al uso de una palabra más de moda entre los numerosos calificativos ambientales o representa un concepto relevante para integrar objetivos de investigación propios de las ciencias sociales y ecológicas. Se recopiló para este análisis una base de datos de publicaciones (n = 1.289) que mencionan el término SSE en su título, palabras clave y/o resumen. Se analizaron afiliaciones de autores, tipo de trabajo (conceptual, empírico, revisión), sitio de estudio, tipo de uso o actividad humana más común, escalas temporales y espaciales de análisis, utilización de variables socioeconómicas y biofísicas en estudios empíricos y uso, en su caso, de métodos que integren ambos tipos de variables. Los resultados obtenidos sugieren que el concepto de SSE se usa ampliamente para estudiar la interfaz entre sistemas sociales y ecológicos. La mayoría de los trabajos muestran algunos elementos comunes, como el análisis de la resiliencia, los servicios de los ecosistemas, la sostenibilidad, la gobernanza y la gestión adaptativa. Sin embargo, la mayoría de los estudios no cumplen el desafío de estudiar el SSE como un todo –como un mismo sistema-, integrando variables sociales y ecológicas y estudiando, entre otros aspectos, sus ciclos de retroalimentación. Los resultados contribuyen a revelar la falta de herramientas útiles para abordar la complejidad de las relaciones sociedad humana-naturaleza y, por ende, que sean aplicables a la gestión de los recursos naturales y a la planificación territorial.

[Este análisis ha sido publicado en *Sustainability*. Impact Factor: 2.075 (2017); 5-Year Impact Factor: 2.177 (2017). Título del artículo: *What do we talk about when we talk about Social-Ecological Systems? A literature review*].

Objetivo b

Para su desarrollo se aplicaron diferentes modelos cuantitativos para explicar los vínculos socio-ecológicos rurales-urbanos, teniendo en cuenta la influencia de la metrópoli de Madrid en la red de municipios vecinos. Los resultados muestran un gradiente de paisaje rural que varía desde usos silvo-pastorales a usos agrícolas y que mantiene diferentes interacciones con la socio-economía local. La polarización urbano-rural y el acceso a la metrópolis son los principales factores de la dinámica del paisaje. La cohesión territorial entre los municipios y la conectividad con la metrópoli son factores que determinan la estructura socio-ecológica del territorio: las zonas de uso preferentemente agrícola del E y SE revelan una buena cohesión social, pero una conexión débil con la ciudad. En el otro extremo, el paisaje occidental y noroccidental dedicado a actividades silvo-pastorales mantiene, por el contrario, vínculos prominentes con la metrópoli y una interconexión no significativa entre sus pequeñas ciudades y pueblos. El procedimiento de estudio aplicado resulta ser una herramienta útil y eficiente para un análisis objetivo de la conectividad socio-ecológica y para evaluar y gestionar estrategias de cohesión territorial.

[Los resultados obtenidos se han publicado en *Urban Ecosystems*. Impact Factor (2017) 2.005. 5-Year Impact Factor: 2.554 (2017). Título del artículo: *Modelling of socio-ecological connectivity. The rural-urban network in the surroundings of Madrid (Central Spain)*].

Objetivo c

En dos áreas de estudio expresamente diferentes -en términos geográficos, interacciones socio-ecológicas y bajo diferentes escenarios de cambio- se ha probado la eficacia de un modelo cuantitativo de análisis, basado en correlaciones canónicas, para determinar el grado de acoplamiento entre sus estructuras ecológicas y socio-económicas. En la primera de ellas, donde se desarrolla esencialmente la presente tesis (Región de Madrid), cualquier observador puede apreciar un alto grado de transformación debida a la expansión urbana e industrial (metropolitana y comarcal), abandono rural y turismo metropolitano de aparente escasa incidencia rural. La segunda (Isla de Fuerteventura, Canarias) destaca por su apariencia desértica y abandono de actividades agrarias tradicionales en contraste con la promoción y desarrollo de un turismo sin la expresa base estacional que tiene lugar en el resto de España.

En la Región de Madrid, un excelente ejemplo de *hotspot* europeo de expansión urbana reciente, el modelo de análisis empleado detecta efectos en el grado de acoplamiento entre socio-economía, bienestar social y pérdida de ruralidad del paisaje a lo largo de un gradiente rural-urbano. Con perspectiva aplicada, el estudio permite proponer estrategias de planificación y gestión ambiental basados en consideraciones sociales y ecológico-rurales.

En Fuerteventura, donde el paisaje también ha cambiado significativamente en las últimas décadas, sus componentes naturales y usos agrarios culturales han disminuido, la población ha aumentado por inmigración, principalmente desde la

España peninsular y otros países europeos. El modelo de estudio aplicado muestra la transición de un socio-ecosistema local a otro basado en un turismo costero que aparta a los habitantes nativos de su paisaje rural cultural. La adaptación al cambio climático es un aspecto crítico para la economía de turismo atemporal característico de las Islas Canarias. Con esta referencia, considerando los cuatro escenarios propuestos por el 'Panel Intergubernamental sobre Cambio Climático', el modelo muestra el consecuente desacoplamiento rural medible en términos de 'desagrarización', 'deruralización' y desarrollo turístico. La cuantificación que aporta el modelo ofrece la posibilidad de simulaciones locales y globales para el Archipiélago Canario complementarias a las observaciones hechas en términos antropológicos culturales (Díaz, 2015).

Los dos casos de estudio demuestran la aplicabilidad del método desarrollado en dos áreas diferentes, independientemente del tipo de relaciones socio-ecológicas que las caracterice. Los resultados fortalecen la validez de las herramientas utilizadas, sobre todo su papel para una planificación territorial sin límites administrativos que facilite la gestión en función de sus necesidades socio-ecológicas.

[Los resultados de estos estudios se han publicado, el primero en *Science of the Total Environment*: Impact Factor (2017): 4.610. 5-Year Impact Factor:4.984. Título del artículo: *Identifying socio-ecological networks in rural-urban gradients: Diagnosis of a changing cultural landscape.* El segundo se ha publicado en *Enviromental Conservation*. Impact Factor (2017): 2.293. 5-Year Impact Factor:2.520. Título del artículo: *People and nature in the Fuerteventura Biosphere Reserve (Canary Islands): socio-ecological relationships under climate change*].

Objetivo d

Para medir, en términos ambientales, la eficacia de la declaración y consiguiente gestión de los ENPs respecto al acoplamiento socio-ecológico y mantenimiento de los SEs, se evaluó la relación entre los cambios de la estructura del paisaje y los *trade-offs* de estos servicios en el tiempo a lo largo del gradiente urbano-rural que constituye el hilo conductor espacial de la presente tesis. Se consideraron dos fechas con un intervalo de más de 20 años (1990 y 2012). Mediante Análisis de Correspondencias Canónicas se detectó una marcada tendencia temporal de cambio hacia paisajes más heterogéneos, cuyos fragmentos presentan un bajo valor de conectividad entre sí. Este cambio estructural está asociado a *trade-offs* de SEs. Hay un claro intercambio de servicios de provisión y regulación, inherentes a los paisajes agrícolas y silvo-pastorales, con los servicios turístico-culturales, demandados sobre todo por la población urbana. Un modelo lineal generalizado permitió relacionar la intensidad del cambio del territorio con la magnitud del desarrollo urbanístico, la proximidad a una ciudad relevante como Madrid y las medidas de protección restrictivas vinculadas a los planes de conservación ligados a la gestión supramunicipal del territorio. Estos resultados cuestionan la eficacia de las medidas de conservación a largo plazo tomadas en España para proteger los paisajes culturales rurales y señalan la necesidad de un cambio en la gestión de estos espacios, que debieran ser prioritarios en el mantenimiento de las actividades tradicionales como componentes marco de la conservación de la naturaleza y del flujo de servicios en gradientes urbano-rurales.

[Los resultados han sido aceptados para su publicación en *Landscape Ecology*. Impact Factor (2017): 3.833. 5-Year Impact Factor: 4.422. Título del artículo: *Aligning landscape structure with ecosystem services along an urban-rural gradient. Trade-offs and transitions towards cultural services*].

Objetivo e

Para valorar los paisajes rurales y su relación con la gestión de los ENPs se consideraron dos aspectos del paisaje rural-cultural: la persistencia o abandono de recintos con setos y su gestión dentro y fuera de las áreas protegidas. Los setos, tradicionalmente usados para manejo del pasto/ganado, tienen una importancia notable para la diversidad biológica natural y cultural y pueden considerarse como indicadores del estado de conservación del paisaje cultural. Los resultados indican que, siendo la gestión sensata del paisaje uno de los objetivos principales de los ENPs, en el territorio estudiado el paisaje rural cultural está abandonándose tanto dentro como fuera de sus límites establecidos. La razón de este abandono puede encontrarse en un exceso de valoración de la 'naturaleza salvaje' (*wilderness*) o 'naturalidad' (*naturalness*) y una falta de atención y pérdida del CET por desconocimiento o desconsideración del papel ecológico de la sociedad rural, más desatendida aún en los sistemas silvo-pastorales que en los agrícolas.

Considerando la incidencia del turismo en el contexto de la gestión del paisaje y las implicaciones en su conservación[1], la tesis incluye un capítulo de libro que muestra cómo los efectos de este factor, hoy particularmente importantes en la cultura mediterránea, interesan ser estudiados desde perspectivas ecológicas y económicas. Se ha considerado, pues, el papel del turismo cultural en la Región Central española, ubicando el análisis en una zona identificada por su elevado valor del paisaje cultural rural de Madrid (el Valle de Lozoya). Se analizó por procedimientos multivariantes así el atractivo del 'mundo rural' para el turismo comparándose encuestas previas realizadas en 2007 con otras realizadas ahora, una década después, en este valle. Los intereses de los visitantes resultaron cambiar sustancialmente en esta década,

[1] Se infiere de los resultados anteriores (objetivo c) obtenidos en la isla de Fuerteventura: la transición del socio-ecosistema local acoplado hacia un sistema de interacción con el turismo costero que desacopla a los habitantes nativos del paisaje y las prácticas rurales.

modificando sus preferencias iniciales por la cultura rural hacia una 'naturaleza silvestre'. En la década transcurrida ha tenido lugar un marcado desacoplamiento socio-ecológico, caracterizado por pérdida de ruralidad y de usos tradicionales, ambos ligados a la expansión urbana de Madrid. Los resultados obtenidos a escala local, con datos obtenidos mediante muestreos de campo, ratifican los obtenidos en los estudios desarrollados a partir de bases de datos públicas, destacando la importancia del CET y de las prácticas tradicionales desarrolladas históricamente por la población local. Los tomadores de decisiones pueden tenerlos en cuenta: su reconocimiento, mejora y aplicación es una vía para disponer de herramientas robustas, inclusivas y efectivas para la gestión y conservación de los paisajes culturales rurales, especialmente los declarados con diferentes categorías de protección.

[Estos últimos estudios acaban de publicarse en dos revistas y como capítulo de libro: *i) Land Degradation and Development*. Impact factor (2017): 7.27. 5-Year Impact Factor: 6.564. Título del artículo: *Evaluating the role of a protected area on hedgerow conservation: the case of a Spanish cultural landscape; ii) Science of the Total Environment*. Impact Factor (2017): 4.610. 5-Year Impact Factor:4.984. Título del artículo: *Losing a heritage hedgerow landscape. Biocultural diversity conservation in a changing social-ecological Mediterranean system*; y *iii) Sustainable Tourism VIII* (2018). WIT Press, Boston: 1-10. [*WIT Transactions on Ecology and The Environment*, 227: 1-10]. SJR (International Science Ranking) H index: 17. Título del capítulo: *Rural tourism. Crossroads between nature, socio-ecological decoupling and urban sprawl*].

6. Discusión

Los sistemas donde aparecen estrechamente vinculados los procesos sociales, económicos, ecológicos, culturales y políticos se han denominado 'sistemas socio-ecológicos' (SSE), resaltando la perspectiva de los 'seres humanos en la naturaleza'. Este término no parece una palabra de moda vacía de significado (*buzzword*). El concepto se ha conformado progresivamente utilizando aportes de diferentes trabajos clave sobre el tema, y hoy en día la mayoría de las publicaciones que usan este término estudian el SSE explícitamente. Sin embargo, la falta de un uso común del concepto en todas las publicaciones analizadas refleja que éste no está claramente definido. Al contrario, parece seguir siendo un concepto en construcción integrado por muchas corrientes de pensamiento mejor o peor organizadas y originadas en el seno de diferentes disciplinas.

Las diferentes escalas espacio-temporales en que operan los procesos sociológicos y ecológicos dificultan encontrar métodos apropiados para combinar ambos tipos de variables, sobre todo procesos, a sus escalas adecuadas, y estudiar el SSE como un todo, con el objetivo de extraer sus propiedades emergentes (Graymore *et al*., 2008; Cooke *et al*., 2009; Easdale & Aguiar, 2012). Un problema frecuente radica en que los datos biofísicos y socioeconómicos y sus análisis respectivos, pueden tener diferentes escalas temporales y espaciales (Giampietro, 1999). Para evitar desajustes entre diferentes bases de datos y generar inferencias sólidas, los datos deberían reunirse en una escala única y comparable, algo que no es un desafío trivial (Cumming *et al.,* 2006; Prince, 2002). De hecho, aunque alrededor del 40% de los estudios empíricos aportan variables tanto biofísicas como sociológicas, apenas la mitad de ellos trata de desarrollar herramientas para integrar ambos conjuntos de variables. Estos esfuerzos tienen bastante éxito y, sobre todo, aplicación, principalmente mediante el uso de sistemas de información geográfica, modelos matemáticos multivariantes, como el análisis de regresión múltiple o el de superficies de tendencias, entre algunos otros, para analizar la correspondencia entre estructuras complejas (de acuerdo con Schmitz *et al*., 2003, 2012, 2017, 2018; De Aranzabal *et al.*, 2008 y Salvati *et al.,* 2009, 2016, 2017). En realidad se trata de considerar el concepto de 'conectividad', empleado en su origen (1969) para conectar entre sí diferentes computadoras, cada una de las cuales son, en sí mismas –individualmente-, mundos complejos (Department of Defense USA, 1969; World Wide Web, 2009; McPherson & Sammartino, 2009). INTERNET, ni siquiera imaginada apenas hace tres décadas -quizá con la excepción de Alan Turing (1912-1954)-, es probablemente el mejor ejemplo de lo que se trata en la presente tesis, donde parece clara la necesidad de desarrollar herramientas metodológicas que combinen diferentes conjuntos de variables y a diferentes escalas.

La aportación de la tesis al proyecto *Ecogradientes* se formula desde esta perspectiva, considerando métodos cuantitativos útiles para la planificación integrada y socio-ecológicamente sostenible de un territorio que se ha considerado en términos de gradientes rural-urbanos. Se hacen así las aproximaciones metodológicas antes referidas, que combinan variables y parámetros de diferente naturaleza para abordar la complejidad de las relaciones socio-ecológicas. Los problemas de tiempo y de escala se salvan mediante el uso de unidades elementales homogéneas de análisis, en este caso unidades administrativas (municipios) y se considera un hecho probado que el proceso de 'metropolización' de un territorio como el estudiado aquí genere una serie de cambios ambientales caracterizados por diferentes y curiosas interacciones entre socio-economía y naturaleza.

Formalización de la conectividad socio-ecológica como base para la planificación del territorio

La 'conectividad socio-ecológica' refiere las características de la conexión, medible y formalizable, entre dos sistemas complejos: uno social y otro ecológico. Las llamadas 'tramas socio-ecológicas' consideran esta conexión como las conexiones ‘internas’ que ocurren en un sistema integrado (‘socio-ecológico’). En nuestro caso, este sistema se ha delimitado espacialmente como Comunidad o Región de Madrid, algo admisible más fácilmente en términos geográficos y administrativos que en términos ecológicos, donde los fenómenos y procesos difícilmente tienen límites espaciales definibles objetivamente. Salvadas estas observaciones, en la Región de Madrid se han encontrado patrones de comportamiento similares a los del entorno de otras ciudades europeas en proceso de expansión urbana y vinculados al estilo de vida de sus habitantes (Antrop, 2000). Mediante análisis multivariantes se ha visto que el patrón socio-ecológico regional detectado está estrechamente relacionado con el desarrollo de las infraestructuras de transporte, que actúan como corredores de movilidad conectando el área urbana con pequeñas ciudades y otros asentamientos dispersos (Forman, 2014). Estas redes de transporte suponen un aumento en la movilidad de personas y recursos, favoreciendo, entre otros, la interconexión entre lugares de residencia y trabajo, el intercambio de bienes e información (Rosell *et al.,* 2003; Serra *et al.,* 2014) y, por lo tanto, la expansión urbana. Esta se expresa como un patrón disperso a lo largo de las principales autovías. La interacción entre la expansión urbana y las nuevas redes de comunicación condiciona la organización espacial del paisaje (Antrop, 2004).

La Perspectiva Europea de Desarrollo Espacial (CEC, 1999) propone un desarrollo policéntrico para contrarrestar los desequilibrios espaciales. En el área de estudio, los modelos económicos y de planificación territorial no se han desarrollado de acuerdo con la lógica de la política de cohesión de la Unión Europea (UE), que establece que las personas no deberían verse perjudicadas por su lugar de residencia y trabajo (Faludi, 2006). La importancia de la conectividad con la metrópolis y la cohesión interna del territorio aparecen relacionadas con la dinámica de la urbanización. En particular, los procesos de urbanización y sus infraestructuras de transporte asociadas definen la relación entre la ciudad y el campo (Antrop, 2004). Madrid mantuvo un modelo de ‘anillos concéntricos’ hasta la década de 1960. Actualmente, como ya se ha indicado, existe un patrón disperso favorecido por el desarrollo de las citadas infraestructuras de transporte (Forman, 2014).

En Europa, muchos territorios rurales desconectados de los sistemas metropolitanos apenas han experimentado cambios en sus actividades económicas tradicionales, que siguen estando estrechamente relacionadas con las demandas de la Política Agraria Común de la Unión Europea. A pesar de esto, está ocurriendo un evidente proceso de despoblación y abandono (Barbero-Sierra *et a*l., 2013). Este es el caso en la zona S-SE de la Región de Madrid. Las zonas despobladas y marginadas del interior de España son similares a las de otros países de Europa central y meridional (Agnoletti *et al.,* 2014).

De acuerdo con un modelo de influencias metropolitanas-rurales, debe considerarse que el desarrollo económico no solo implica crecimiento y que las relaciones territorio-recurso y territorio-problema deben ser consideradas. La dicotomía urbano-rural a lo largo del gradiente de paisaje estudiado puede entenderse como un desplazamiento del grado de influencia humana de paisajes rurales a urbanos, incluidos procesos socio-ecológicos, sin duda debidos a flujos medibles según qué casos (energía, bienes, servicios, personas, capital e información; Modica *et al.,* 2012). Sin embargo, pocos estudios relevantes desarrollados en España abordan dinámicas territoriales medidas y analizadas considerando el concepto de conectividad aquí contemplado (ver, en relación con ello, Rosell *et al.,* 2003; Pineda & Schmitz, 2011), el de movilidad entre lugares de residencia y trabajo (Serra *et al.,* 2014) o los efectos ecológicos de las diferentes tendencias de urbanización (Redman *et al.,* 2004; Zhao *et al.*, 2006; Xun *et al.,* 2017). Existe, pues, una carencia de estudios que formalicen metodológicamente conectividad y tramas socio-ecológicas a escalas que permitan gestionar el territorio más allá de los límites administrativos (Arnaiz-Schmitz *et al.,* 2018*b*).

Planeamiento territorial convencional y desacoplamiento socio-ecológico

Uno de los resultados que podrían considerarse más polémicos de la tesis indica que el aumento de uso de suelo urbano e industrial está relacionado con el establecimiento de ENPs. El modelo de gestión de éstos se desarrolla a través de los Planes Rectores de Uso y Gestión (PRUGs), que articulan directrices de gestión y conservación que rompen la conectividad socio-ecológica (Ruiz-Labourdette *et al.,* 2010). Así, aunque las estrategias de planificación generalmente propuestas para regular y controlar el desarrollo urbano en áreas naturales y rurales incluyan el establecimiento de ENPs para conservar la naturaleza (Lambin & Meyfroidt, 2011), nuestros resultados sugieren que las áreas protegidas favorecen, en lugar de evitar, el desarrollo de asentamientos humanos en sus áreas de influencia socioeconómica circundantes. Esto implica un acercamiento espacial no deseable entre los ENPs y las ciudades y resalta la amenaza potencial para la conservación de la biodiversidad. Junto a esto, la gestión dificulta seriamente el mantenimiento de actividades tradicionales, el de la calidad de vida de las poblaciones locales y la propia eficacia de los ENPs. El bienestar social, entendido como la capacidad de las personas para satisfacer sus necesidades básicas y múltiples en el contexto de una equidad económica (Summers & Smith, 2014), se maximiza en las zonas anexas al núcleo central de la metrópoli (sistemas periurbanos). Estas áreas brindan una amplia variedad de servicios a la sociedad que benefician a todos los estratos sociales (Douglas, 2006), reuniendo estilos de vida y actividades económicas tanto rurales como urbanas y estando ocupados por personas de diferentes niveles sociales. Además, estas áreas dentro del gradiente urbano-rural, son zonas críticas de cambio en los UCS tradicionales. El cambio de las relaciones socio-ecológicas de los sistemas rurales a los urbanos causa un desacoplamiento rural de consecuencias ambientales nefastas y ajenas a una gestión sensata de los recursos naturales (en realidad esta es la idea de conservación de la naturaleza en un espacio propio de la Cuenca Mediterránea). La expansión urbana implica la transformación de paisajes rurales y naturales en sistemas urbanos, modificando complejas relaciones socio-ecológicas a través de cambios económicos y demográficos (Antrop, 2004; Seto *et al.,* 2010). Las circunstancias mencionadas generan alteraciones en las funciones y procesos ecológicos que dependen del flujo de energía y material propios del paisaje (Palacios *et al.,* 2013; Arnaiz-Schmitz *et al.,* 2018*a*) y amenaza la sostenibilidad de los SSEs. La comparación de la provisión de SEs en las regiones urbanas y sus zonas rurales interiores puede proporcionar evidencias que respalden el desarrollo de estrategias efectivas de planificación del territorio (Lindenmayer & Fischer, 2013).

Marco de referencia de los servicios de los ecosistemas en gradientes rural-urbanos. Planificación territorial más allá de los límites administrativos

Las interacciones recíprocas entre los usos del suelo a lo largo de los gradientes urbano-rurales juegan un papel clave en la provisión de servicios a los seres humanos (Burkhard *et al.,* 2012; Maskell *et al.*, 2013; Hou *et al.,* 2015). A pesar de ello, los vínculos entre los SEs y los aspectos socio-ecológicos apenas se han considerado en este marco de referencia. En esta tesis se ha estudiado el cambio temporal de la relación entre el suministro de servicios y la estructura del paisaje en el citado gradiente urbano-rural. La existencia de *trade-offs* de los servicios de aprovisionamiento y regulación por los servicios culturales resultan ser demandados principalmente por la población urbana. El proceso está asociado al cambio gradual de los patrones de paisaje tradicionales hacia áreas caracterizadas por una mezcla heterogénea de tipos de uso del suelo contrastados y poco conectados. Esto se ha encontrado en otros casos de la misma región (Arnaiz-Schmitz *et al.,* 2018*a*) y otras áreas mediterráneas (Marchetti *et al.,* 2014). En el área de estudio, la dinámica general descrita se relaciona con el proceso general de transición en el gradiente urbano-rural de los sectores socioeconómicos primarios a terciarios, esencialmente debido al aumento del turismo (Antošová, 2014; Schmitz *et al.,* 2007). En España, este proceso es especialmente relevante probablemente por el rápido abandono de las actividades rurales tradicionales y la despoblación de las zonas rurales como resultado de las disparidades económicas regionales -en gran medida han sido estimuladas por muchas de las restricciones que la UE ha impuesto a las actividades de pequeña producción (Baldock & Long.1998; Barrios & Strobl, 2009; Palomo *et al.,* 2013; Tirado *et al.,* 2016)-. La tendencia del cambio vinculada al abandono rural y la expansión urbana han traído consigo un notable proceso de desacoplamiento socio-ecológico y pérdida de la ruralidad.

En cualquier caso, el fenómeno resulta atractivo para el turismo cultural, poniendo la balanza a favor de la conservación de la naturaleza frente al mantenimiento de las actividades tradicionales de la población local (Arnaiz-Schmitz *et al.,* 2018*c*).

Los resultados también señalan la relación entre la presencia de figuras de protección de la naturaleza y el cambio de la interacción entre los SEs y la estructura del paisaje. La planificación municipal que incluye en su diseño a la red Natura 2000 o a las Reservas de la Biosfera es más eficiente frenando la tasa de pérdida de SEs observada desde el sector primario hacia el sector terciario. Esto garantizaría el mantenimiento de los SEs de provisión y regulación. Sin embargo, los esquemas supramunicipales de ordenamiento territorial administrados por los Parques Regionales y Nacionales no han impedido la transición de los SEs hacia servicios culturales demandados por la población urbana, tales como el ocio al aire libre y el turismo de naturaleza. Este aspecto también se ha observado en otros ENPs en España (Martín-López *et al.,* 2012) y parece indicar que la planificación territorial es más eficiente a nivel municipal que supramunicipal (Palomo *et al.,* 2014). Además, los resultados sugieren que el Parque Nacional de la Sierra de Guadarrama, creado en 2013, se ha establecido en áreas de apariencia más natural, donde las actividades rurales estaban abandonándose activamente. Una idea malentendida de preservación de la naturaleza favorece la vida salvaje y natural en lugar de los altos valores de conservación reconocidos en los paisajes culturales (Plieninger, 2006, Petanidou *et al.,* 2008, Schmitz *et al.,* 2017) como también se ha visto en otras áreas protegidas, como el Parque Nacional Picos de Europa (Bunce *et al.,* 1998; Rescia *et al.,* 2008). Todo ello cuestiona la eficacia de las medidas de protección que imponen restricciones a los usos del suelo y a las actividades rurales tradicionales, en lugar de promover políticas públicas para mantener a las poblaciones rurales y al paisaje cultural, altamente valorado y con un mayor potencial para expandir la oferta de SEs (Schaich *et al.,* 2010).

Conservación de paisajes culturales y actividades económicas tradicionales. El papel de los setos como indicadores.

Para estudiar en detalle el fenómeno de abandono rural asociado al establecimiento de ENPs, se han hecho diferentes análisis a escala local sobre el estado de conservación del paisaje cultural rural dentro y fuera de estas áreas. Para ello se ha utilizado como indicador del estado de conservación del paisaje la red relicta de setos identificada dentro del área de estudio (Schmitz *et al.,* 2017; Arnaiz-Schmitz *et al*., 2018*d*), dada su potencialidad ecológica, naturalista, social y productiva (Forman & Baudry, 1984; Forman & Godron, 1986; Burel & Baudry, 1995; Busck, 2003). Las redes de setos proporcionan conexiones entre diferentes sitios y sirven de corredores para algunos organismos (McCollin *et al.,* 2000). Por ello son estructuras reconocidas como de alto valor ecológico y paisajístico, reconocidas internacionalmente mediante elevados *status* de protección, particularmente Gran Bretaña es un ejemplo paradigmático de su valoración.

En la Región Mediterránea, las estructuras de setos vivos datan de la antigüedad, son parte importante de los sistemas agro-silvo-pastorales tradicionales y constituyen un buen ejemplo de integración de las actividades agrícolas y ganaderas en el paisaje rural (Paoletti *et al.,* 2001). Por ello, los setos contribuyen a la conectividad y funcionalidad de los paisajes culturales y su valor ecológico e histórico debe ser considerado en los esquemas de planificación y conservación del territorio (Schmitz *et al.,* 2007). En el área de estudio el abandono en las últimas décadas de los sistemas ganaderos tradicionales (pastizales y dehesas) ha resultado en la pérdida de antiguos paisajes culturales con setos.

Los resultados obtenidos en el presente trabajo advierten sobre la gestión inadecuada del paisaje de setos, que comporta una drástica pérdida de setos multifuncionales, tanto por abandono como por eliminación. En este contexto, el análisis de la dinámica de la red en el área de estudio, que comprende un área protegida y sus espacios circundantes, indica que el esquema normativo de protección territorial no está impidiendo la pérdida de este tipo de paisaje, sometido a un notable proceso de fragmentación y eliminación. La tendencia al abandono o al mantenimiento de los setos resulta ser equivalente dentro y fuera de los límites de un área protegida, revelando la falta de eficacia de las figuras de protección para cumplir sus objetivos. La ineficacia del manejo y evaluación de los ENPs queda en evidencia con la tasa de pérdida de especies dentro de sus límites, mayor que en el resto del territorio, y en el hecho de que algunas especies desaparecidas están catalogadas en listas de referencia para la conservación de ‘especies con un alto estado de protección’. El futuro de los paisajes de setos depende de la dinámica de la sociedad rural, que actualmente tiende hacia el declive de sus actividades tradicionales y hacia una nueva economía rural no agrícola (Burel, 1996; Schmitz *et al.,* 2012). Varios países europeos incluyen la gestión de setos en sus Esquemas Agroambientales (Baudry *et al.,* 2000; Fuentes-Montemayor *et al.,* 2011) reconociendo su importancia y proporcionando incentivos para su conservación (Barr & Gillespie, 2000; Kleijn & Sutherland, 2003; Schleyer & Plieninger, 2011; Sklenicka *et al.,* 2017). Una buena gestión de los setos tiene costes, de manera que parecen obviamente necesarias unas políticas que contemplen su conservación y fondos disponibles para ello (Hinsley & Bellamy, 2000). Consecuentemente, en un marco político ambiental adecuado, debe apoyarse a los agricultores con subsidios públicos para gestionar redes de setos y beneficiar a la vida silvestre (Boughey *et al.,* 2011).

A pesar de su importancia socio-ecológica, los paisajes de setos no se mencionan en los planes de manejo de los ENPs del centro de España y apenas se mencionan en otras áreas protegidas españolas. Las políticas gubernamentales no han valorado su importancia histórica y cultural ni su actual vulnerabilidad. Puede interpretarse esto como muestra de una cierta debilidad en el manejo de paisajes culturales protegidos: …“aprender de los sistemas de gestión tradicionales es importante para ampliar los objetivos y enfoques de la conservación” (Berkes & Davidson-Hunt, 2006). Además, el hecho de que la mayoría de los planes de gestión estén limitados por fronteras administrativas, en lugar de basarse en relaciones socio-ecológicas y flujos de SEs (Martín-López *et al.,* 2011), acentúa su ineficacia cuando se trata de proteger paisajes de setos intermunicipales.

Propuestas para la planificación socio-ecológica del territorio en un gradiente rural-urbano

La tesis contempla el desarrollo de herramientas metodológicas que faciliten la identificación y gestión de conflictos entre actividades humanas y conservación de la naturaleza. El abandono de las actividades y usos agrarios tradicionales y el desarrollo urbanístico se identifican como conflictos entre los principales ‘impulsores de cambio global’. Se pretende aportar, en consecuencia, un conjunto de recomendaciones o soluciones importantes para la ‘toma de decisiones’ en la planificación del territorio y el mantenimiento del flujo de SEs en gradientes urbano-rurales (McDonnell & Picket, 1990). Los resultados subrayan la necesidad de un cambio conceptual en el planeamiento territorial convencional a nivel municipal, como los Planes Generales de

Ordenación Urbana (PGOUs), y supramunicipal, como los Planes Rectores de Uso y Gestión (PRUGs).

Con la actual y creciente globalización y un desarrollo económico/tecnológico continuo, la interdependencia entre sectores urbano y rural tiende a fracturarse, dando lugar a sistemas socio-ecológicos desacoplados con economías rurales y urbanas separadas. Cumming (2014) ha desarrollado un modelo conceptual basado en el desacoplamiento entre naturaleza y sociedad por medio de bucles o circuitos de retroalimentación. En este modelo, el equilibrio local o acoplamiento entre el uso de los recursos y el tamaño de la población humana ('bucle verde') evita a largo plazo la degradación de los ecosistemas. A medida que se intensifica la relación entre sociedad y naturaleza un bucle verde refleja una dinámica de ruptura o desacoplamiento. Esto ocurre, por ejemplo, cuando una población humana crece a consecuencia de un cambio tecnológico que aumente el suministro de alimentos y la esperanza de vida. La densidad de población y de las infraestructuras aumentan a medida que los asentamientos urbanos crean oportunidades de medios de vida alternativos, brindan seguridad y aumentan la complejidad económica, social y política. En contraposición, los habitantes urbanos tienen generalmente menos contacto con su base de recursos primarios. Estos cambios transforman gradualmente un sistema que se encuentra en bucle verde en otro en 'bucle rojo', que puede convertirse en el régimen dominante que impulse el uso de los SEs. Con el tiempo se reduce la capacidad de los ecosistemas locales para suministrar una gama amplia de SEs a los asentamientos humanos en crecimiento.

Varios de los resultados presentados en esta tesis muestran cómo el modelo conceptual descrito tiene lugar en los gradientes urbano-rurales estudiados. En la 'metropolización' de una región se establecen vínculos entre diferentes núcleos de población que aceleran la pérdida de actividades económicas vinculadas a la base biofísica territorial, donde hasta el momento se habían desarrollado, intercambiando estas actividades por otras independientes de sus UCS. Esto desencadena un desacoplamiento socio-ecológico cuya gestión se convierte en una acción necesaria para evitar que se pierdan los vínculos históricos establecidos que generaron los paisajes culturales tradicionales de alto valor reconocido.

Los resultados (Arnaiz-Schmitz *et al*., 2018*a*) son un ejemplo evidente de este desacoplamiento. Por varios motivos este estudio es uno de los ejes principales sobre los que se desarrolla la tesis. Como se ha mencionado ya, esta investigación caracteriza el gradiente rural-urbano de la Región de Madrid detectando cuatro grupos de municipios que comparten características similares en sus relaciones socio-ecológicas. Es destacable que, además de un gradiente rural-urbano, se identifica otro gradiente de desacoplamiento entre las estructuras biofísica y socio-económica, donde, a medida que los municipios del área contemplada intercambian sus actividades vinculadas al uso de la tierra por otro tipo de actividad económica, se alteran sus tramas socio-ecológicas, perdiéndose su carácter rural y transformándose gradualmente en sistemas más urbanos, independientemente de su posición geográfica. En este proceso se revelan algunos factores clave para la gestión y planificación del territorio, como el papel de la conectividad socio-ecológica, el de los ENPs o el bienestar de los habitantes de un municipio (Arnaiz-Schmitz *et al.* 2018*a,b,c,d*).

La Figura 3, basada en el modelo de Cumming (2014), señala las posibles implicaciones que el desacoplamiento socio-ecológico tiene sobre el flujo de SEs, la socio-economía local y los UCS del territorio estudiado.

En cuanto al papel de los ENPs y sus implicaciones en el desacoplamiento economía local-paisaje, parece claro que la declaración y la gestión de tales espacios especialmente diseñados para la protección del paisaje cultural, están motivando en la práctica la pérdida de actividades tradicionales e incentivando un tipo de conservación que favorece más el abandono de la tierra que su gestión tradicional, productiva dentro del marco de condiciones ambientales de este territorio. Los resultados también señalan la pérdida de CET, algo muy importante para el mantenimiento de estas actividades (Arnaiz-Schmitz *et al*., 2018*d*). Igualmente, el desarrollo de un turismo basado en la naturaleza y las preferencias de los visitantes de por las 'áreas silvestres' están favoreciendo la ruptura de tramas socio-ecológicas tradicionales que han mantenido secularmente el paisaje rural cultural de la región (Arnaiz-Schmitz *et al*., 2018*c*). Estos fenómenos se reflejan también en otros resultados (Herrero-Jáuregui *et al.,* 2018*b*) que señalan un cambio de los servicios de provisión y regulación por los culturales vinculados a actividades terciarias, como el turismo, demostrando de nuevo la ineficacia de la gestión del paisaje dentro en el área de estudio.

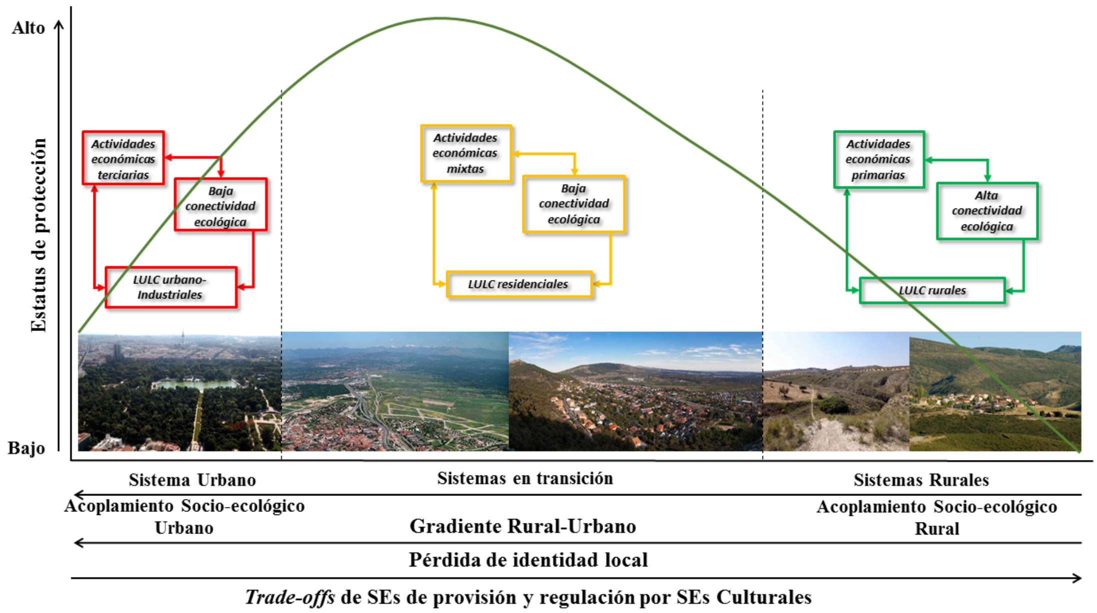

Figura 3. Variación socio-ecológica identificada en el gradiente rural-urbano de la Región de Madrid. Esquema general inspirado en el modelo teórico de Cumming (2014) y basado en los resultados de Arnaiz-Schmitz *et al.,* (2018*a*).

La conectividad socio-ecológica es otro de los procesos clave que deben contemplarse en los estudios territoriales y el planeamiento urbanístico. La tesis detecta un alto grado de conectividad intermunicipal que contribuye significativamente al desarrollo regional junto al fortalecimiento de la cultura y la identidad locales y el arraigo de sus habitantes (Arnaiz-Schmitz *et al.,* 2018*b*). La sustitución de las relaciones intermunicipales por una intensa relación con la metrópoli favorece, en cambio, la pérdida de esta identidad. Las herramientas metodológicas propuestas en la tesis permiten identificar los puntos críticos de territorios que requieren intervenir eficazmente modificando su gestión e impedir el desacoplamiento y la consecuente pérdida ecológica y cultural e identidad local de sus habitantes.

Los procesos esenciales detectados permiten sentar las bases para abordar una planificación socio-ecológica del territorio. Así, a partir de los resultados y conclusiones aportadas por los métodos cuantitativos aplicados en los diferentes estudios de esta tesis y con el objetivo de mitigar los procesos de desacoplamiento socio-ecológico detectados, se han elaborado las siguientes propuestas vinculadas a la planificación y gestión socio-ecológicas del territorio:

i) Aplicación de instrumentos políticos y económicos que favorezcan el mantenimiento de las actividades rurales tradicionales, especialmente en los ENPs y en sus áreas de influencia socioeconómica;

ii) Desarrollo de una red adecuada de infraestructuras que favorezca la conexión entre municipios vecinos y permita reforzar la cultura y la identidad local, evitando el alto grado de dependencia con la metrópolis;

iii) Generación de espacios de educación ambiental y de promoción del turismo cultural y de naturaleza basados en el valor del paisaje rural y de sus actividades económicas asociadas, que favorezcan al mantenimiento de este paisaje, la calidad de vida de las poblaciones locales y su desarrollo económico.

7. Conclusiones

1. El término 'sistema socio-ecológico' (SSE) no parece ser una palabra de moda y sin significado claro entre algunas de las que acompañan hoy en día a la popularidad de 'la ecología' o 'el medioambiente'. Es un concepto aún en construcción propio de la transición entre las ciencias sociales y ecológicas, con aportes de diferentes materias convergentes en una idea que invita a la comunicación entre varias áreas de conocimiento. En la actualidad la mayoría de las publicaciones científicas que utilizan este término se refieren de forma explícita al SSE.
2. Sería deseable una definición compartida de SSE que ayudara a consolidar el concepto en el contexto de las ciencias que emergen en torno a la idea de sostenibilidad.
3. Dentro de este marco pueden desarrollarse esquemas e instrumentos de ordenación territorial y escenarios de cambio que impliquen conflictos sociales detectables a diferentes escalas espacio-temporales. Para ello debe contarse con herramientas metodológicas como las empleadas en esta tesis que permitan integrar datos sociales y biofísicos a resoluciones espacio-temporales adecuadas para su aplicación a diferentes escalas espaciales y temporales.
4. Los modelos cuantitativos aquí ensayados, de diferente grado de complejidad, permiten formalizar la relación entre la estructura del paisaje cultural y la socioeconomía, cuantificar su grado de acoplamiento, deducir indicadores de esta relación –como la relativa a la dualidad ser humano-naturaleza (Humanidad-resto de la Ecosfera)– y predecir su evolución simulando cambios ambientales. Los indicadores detectados se refieren a la conectividad entre naturaleza y sistemas humanos en términos de redes o tramas socio-ecológicas existentes en una región y desarrollo económico dados.
5. En los casos estudiados, estos modelos son una herramienta útil para analizar y cuantificar la conectividad socio-ecológica y, de acuerdo con ella, diseñar y promover políticas orientadas a la cohesión territorial. El modelo ensayado en

la Región de Madrid detecta gradientes ambientales con clara diferenciación del carácter rural de los municipios según sus usos del suelo sean silvo-pastorales o agrícolas. En ambos casos, la distancia y accesibilidad a la metrópoli determinan la estructura socio-ecológica y el grado de cohesión territorial de esos municipios.

6. El análisis realizado en la Región de Madrid diferencia tipos de municipios y los caracteriza mediante métricas de paisaje y *proxis* de bienestar social a lo largo de un gradiente urbano-rural. El acoplamiento socio-ecológico resulta ser alto tanto en las áreas urbanas como en las rurales, aunque sus características son diferentes. Así, el medio rural, ligado al sector primario, es altamente heterogéneo y cambia gradualmente hacia un sistema urbano, vinculado al sector terciario, que presenta también paisajes heterogéneos, pero con unidades espaciales o fragmentos muy contrastados y desconectados. En ninguno de los dos tipos de paisaje se alcanzan niveles altos de bienestar social. Las áreas periurbanas y las rurales en transición hacia sistemas urbanos, muestran desacoplamientos entre socioeconomía y naturaleza, así como un paisaje con tendencia a la fragmentación y desconexión espacial. En las áreas de transición la población disfruta, sin embargo, de los más altos niveles de bienestar y nivel de vida de la región.
7. La configuración de las tramas socio-ecológicas de la Región de Madrid está estrechamente relacionada con la calidad y el desarrollo de las infraestructuras de transporte, a lo largo de las cuales se han producido intensos procesos de expansión y crecimiento urbano.
8. Las tramas socio-ecológicas del territorio se reflejan en diferentes configuraciones espaciales con influencia significativa en el suministro de SEs. La interacción estructura del paisaje-SEs en el gradiente urbano-rural de la región de Madrid muestra un elevado acoplamiento. Los paisajes agrícolas, espacialmente homogéneos, están asociados con servicios de provisión y los silvo-pastorales, más heterogéneos, con servicios de provisión y regulación. Hay un cambio estructural evidente en el tiempo, desde paisajes homogéneos a otros heterogéneos. Esto supone un *trade-off* de servicios de provisión y regulación por SEs culturales. La intensidad del cambio de las interacciones entre los patrones espaciales del paisaje y los SEs aumenta con la urbanización, la proximidad a la metrópoli y las medidas restrictivas de protección del territorio –generalmente esquemas de conservación gestionados a niveles supramunicipales–.

9. La conservación de paisajes rurales culturales y de sus SEs asociados, está vinculada al mantenimiento de las actividades tradicionales. El estado de las redes de setos puede considerarse, a su vez, indicador del estado de conservación de estos paisajes. Tienen un papel clave en el mantenimiento de la biodiversidad natural y cultural (razas, variedades y formas de organismos domesticados) y en la funcionalidad ecológica, social e histórica del territorio. La red relicta de setos de origen medieval del NW de la Región de Madrid es objeto de un penoso abandono, degradación y desatención por parte de la administración ambiental de este territorio. La declaración de diferentes ENPs no ha mitigado la degradación de este paisaje.
10. El mantenimiento de los paisajes rurales culturales que persisten en la Región de Madrid y que incluyen categorías de protección reconocidas como 'de alto valor ecológico, natural y cultural', requiere mayor atención institucional y una eficaz gestión participativa. Así, el análisis desarrollado en el Valle del Lozoya, reconocido con diferentes categorías de protección, ha permitido detectar un claro desacoplamiento socio-ecológico ligado a la expansión urbana y a la pérdida de actividades tradicionales y de población rural. Vinculado a este proceso, y teniendo en cuenta la importancia socioeconómica de la industria turística en Madrid, se ha detectado una disminución en la valoración del paisaje rural por sus visitantes y un aumento en sus preferencias por la 'naturalidad'. Esto señala ineficacias de la gestión del paisaje y la necesidad de promover un turismo cultural basado en el mantenimiento de las actividades rurales que generaron este paisaje, priorizándolas como medida de protección de la naturaleza y desarrollo económico de las poblaciones locales.
11. Viene cuestionándose en los últimos años la eficacia de las medidas para conservar la naturaleza y la biodiversidad. Una gestión sin duda inadecuada de los ENPs ha descuidado o restringido las actividades rurales y facilitado el abandono y consecuente degradación de paisajes multifuncionales patrimoniales. Se recomienda, en consecuencia, establecer incentivos que fomenten esas actividades dentro y fuera de los ENPs.
12. El modelo de estudio, aplicado en dos territorios expresamente contrastados – la Región de Madrid y la Isla de Fuerteventura– demuestra ser una buena herramienta para el análisis y la caracterización del territorio y útil para la planificación socio-ecológica.
13. Por su parte, el análisis socio-ecológico ensayado en Fuerteventura detecta subsistemas con diferentes grados de acoplamiento. En términos sociales, esto depende aquí de la variación de la tipología de sus habitantes: población local

y no nativos, principalmente peninsulares. La población local responde a la patrimonialización de los méritos reconocidos a las zonas rurales, actualmente objeto de 'desruralización', y la no nativa tiende a asociarse con el desarrollo del sistema turístico. Los sistemas acoplados al turismo parecen desarrollarse paralelamente al proceso de desacoplamiento local.

14. Los escenarios de cambio climático ensayados en el modelo de relación aplicado, teniendo en consideración la importancia del turismo en las Islas Canarias, indican una tendencia a aumentar tanto el desacoplamiento de los sistemas locales como el acoplamiento de los sistemas turísticos. El desacoplamiento rural ocurre en las zonas tampón y núcleo de la Reserva de la Biosfera de esta isla, que abarca todo su territorio. Tampoco la declaración y zonificación de este ENP en Canarias ha previsto el desacoplamiento de la relación secular entre la población local y la naturaleza en un territorio muy ligado a la industria turística.
15. Aunque los resultados de esta tesis deben considerarse sobre todo en el contexto económico de la principal región estudiada -la Comunidad de Madrid-, los modelos aplicados son útiles para identificar factores predominantes en las tramas socio-ecológicas territoriales, incluso en territorios de características muy contrastadas como los dos contemplados.
16. La clasificación espacial de tipos socio-ecológicos y la cuantificación de su grado de acoplamiento biofísico y socioeconómico, deben considerarse en los esquemas de gestión ambiental más allá de los límites municipales, especialmente en áreas sujetas a intensas tendencias de expansión urbana y pérdida de ruralidad. Comprender la relación espacio-temporal entre la estructura del paisaje y sus SEs supone una información única para desarrollar opciones más efectivas de planificación y gobernanza del territorio, predecir tendencias en diferentes lugares y facilitar la integración de los objetivos socio-ecológicos en la toma de decisiones político-económicas.

8. Conclusions

1. The term 'social-ecological system' (SES) does not seem to be a trendy term and has no clear meaning among some of those that nowadays accompany the popularity of 'ecology' or 'the environment'. It is a concept still under construction, part of the transition between social and ecological sciences, with contributions from different converging subjects into an idea that encourages the communication between several areas of knowledge. Currently, most scientific publications that use this term refer explicitly to SES.

2. A shared definition of SES would be desirable to help consolidate the concept in the context of those sciences that emerge around the idea of sustainability.
3. Within this framework, schemes and instruments can be developed for land planning and change scenarios that involve social conflicts detectable at different spatial-temporal scales. To this end, methodological tools such as those used in this thesis should be available to integrate social and biophysical data at spatial-temporal resolutions suitable for their application at different scales.
4. The quantitative models tested here, of different degree of complexity, allow to formalize the relationship between the structure of the cultural landscape and the socioeconomy and to quantify their degree of coupling. It also allow to deduce the indicators of this relationship –such as the one related to the duality of human being-nature (Humanity-rest of the Ecosphere) - and to predict its evolution by simulating environmental changes. The detected indicators refer to the connectivity between nature and human systems in terms of existing social-ecological webs or networks in a given region and economic development.
5. In the cases studied, these models are a useful tool to analyse and quantify social-ecological connectivity, and in accordance, design and promote policies aimed at territorial cohesion. The model tested in the Madrid Region detects environmental gradients with a clear differentiation of the rural character of the municipalities according to whether their land uses are silvo-pastoral or agricultural. In both cases, the distance and accessibility to the metropolis determine the social-ecological structure and the degree of territorial cohesion of those municipalities.
6. The analysis carried out in the Madrid Region differentiates types of municipalities and characterizes them through landscape metrics and social welfare proxies along an urban-rural gradient. The social-ecological coupling turns out to be high in both urban and rural areas, although their characteristics are different. Thus, the rural environment linked to the primary sector is highly heterogeneous and gradually changes towards an urban system linked to the tertiary sector. This system also presents heterogeneous landscapes, but with spatial units or fragments very contrasted and disconnected. In neither of the two types of landscape are high levels of social welfare achieved. The peri-urban and rural areas in transition to urban systems show decoupling between socioeconomy and nature, as well as a landscape with a tendency towards fragmentation and spatial disconnection. In the transitional areas, the population

enjoys, nevertheless, the highest levels of well-being and standard of living in the region.

7. The configuration of the social-ecological webs of the Madrid Region is closely related to the quality and development of transport infrastructures, along which intense processes of expansion and urban growth have taken place.
8. The social-ecological webs of the territory are reflected in different spatial configurations with significant influence on the supply of ESs. The interaction structure of the landscape-ESs in the urban-rural gradient of the Madrid region shows a high coupling. Agricultural landscapes, spatially homogeneous, are associated with provisioning services and silvo-pastoral landscapes, more heterogeneous, are associated with provisioning and regulation services. There is an evident structural change over time, from homogenous to heterogeneous landscapes. This means a trade-off of provisioning and regulation services by cultural ESs. The intensity of change in the interactions between the spatial patterns of the landscape and the ESs increases with the urbanization process, the proximity to the metropolis and the restrictive measures for the protection of the territory -generally conservation schemes managed at supramunicipal levels-.
9. The conservation of rural cultural landscapes and their associated ESs is linked to the maintenance of traditional activities. The status of the hedgerow networks can be considered, in turn, an indicator of the state of conservation of these landscapes. They have a key role in the maintenance of natural and cultural biodiversity (breeds, varieties and forms of domesticated organisms) and in the ecological, social and historical functionality of the territory. The relict hedge network of medieval origin in the NW of the Madrid Region is object of a painful abandonment, degradation and neglect on the part of the environmental administration of this territory. The declaration of different PAs has not mitigated the degradation of this landscape.
10. The maintenance of rural cultural landscapes that remain in the Madrid Region and that include categories of protection recognized as 'of high ecological, natural and cultural value', requires greater institutional attention and effective participatory management. Thus, the analysis carried out in the Lozoya Valley, recognized with different protection categories, has made possible the detection of a clear social-ecological decoupling linked to the urban expansion and the loss of traditional activities and rural populations. Linked to this process, and taking into account the socioeconomic importance of the tourism industry in Madrid, there has been a decrease in the appreciation of the rural landscape by

its visitors and an increase in their preferences for 'naturalness'. This indicates inefficiencies in the management of the landscape and the need to promote a cultural tourism based on the maintenance of the rural activities that generated this landscape, giving them priority as a measure to protect the nature and economic development of local populations.

11. In recent years, the effectiveness of nature and biodiversity conservation measures has been questioned. An undoubtedly inadequate management of PAs has neglected or restricted rural activities and has facilitated the abandonment and consequent degradation of multifunctional heritage landscapes. It is recommended, therefore, to establish incentives that encourage these activities inside and outside of the PAs.
12. The model, applied in two territories expressly contrasted -the Madrid Region and the Island of Fuerteventura- proves to be a good tool for the analysis and characterization of the territory and useful for social-ecological land planning.
13. In turn, the social-ecological analysis tested in Fuerteventura detects subsystems with different degrees of coupling. In social terms, this depends on the variation of the typology of its inhabitants: local people and non-natives, mainly peninsular. The local population responds to the patrimonialization of the merits recognized to rural areas, which are currently the object of deruralization, and the non-native population tends to be associated with the development of the tourism system. Tourism coupled systems seem to develop concurrently to the process of local decoupling.
14. The climate change scenarios tested in the applied relationship model, taking into account the importance of tourism in the Canary Islands, indicate a tendency to increase both the decoupling of local systems and the coupling of tourism systems. The rural decoupling occurs in the buffer and core zones of the Biosphere Reserve of this island, which covers its entire territory. Neither the declaration nor the zoning of this PA in the Canary Islands has foreseen the decoupling of the secular relationship between local population and nature in a territory closely linked to the tourism industry.
15. Although the results of this thesis should be considered mostly in the economic context of the main region studied -the Community of Madrid-, the applied models are useful to identify predominant factors in social-ecological webs, even in territories with highly contrasted characteristics as the two considered.
16. The spatial classification of social-ecological types and the quantification of their degree of biophysical and socioeconomic coupling should be taken into account in environmental management schemes beyond municipal boundaries,

especially in areas subject to intense urban expansion trends and loss of rurality. Understanding the spatial-temporal relationship between the structure of the landscape and its ESs provides unique information to develop more effective land planning and governance options for the territory, predict trends in different locations and facilitate the integration of social-ecological objectives in political-economic decision-making.

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Glosario de términos

Acoplamiento/desacoplamiento socio-ecológico. Grado de correspondencia entre las diferentes formas de habitar y utilizar el territorio y las estructuras del paisaje por el ser humano (modificado de Gatzweiler 2014).

Biodiversidad. Cantidad, variedad y variabilidad de organismos vivos en un lugar determinado (Margalef 2002).

Conectividad socio-ecológica. Capacidad de conexión entre sistemas biofísicos y sociales (Pineda y Schmitz 2011).

Conocimiento ecológico tradicional (TEK). Conocimiento acumulado a lo largo de muchas generaciones de una estrecha interacción entre las personas y la naturaleza (Drew 2005).

Demanda de servicios de los ecosistemas: La cantidad de un servicio requerido o deseado por la sociedad (Villamagna et al. 2013).

Deruralización. Pérdida de áreas rurales debido a un cambio socioeconómico significativo (Schmitz et al. 2018).

Desagrarización. Proceso de disminución de las actividades agrarias (Schmitz et al. 2018).

Diversidad biológica. Organización biológica resultante de las interacciones probables de las especies en un lugar y un momento determinado (Margalef 2002).

Ecosistema. Conjunto de fenómenos físicos (abióticos), procesos biológicos y culturales interrelacionados basados en flujos de energía (Pineda 2018).

Gestión adaptativa. Proceso sistemático para mejorar y modificar continuamente las políticas, decisiones y prácticas de gestión para lograr los objetivos de conservación a través de una mejor comprensión de los procesos ecológicos (modificado de Lee 1993).

Gestión participativa. Forma de gestión de recursos en la que las partes interesadas de la comunidad local comparten responsabilidades con los organismos institucionales nacionales (Warner 1997).

Gobernanza. Manera de gobernar referida a estructuras y procesos diseñados para garantizar la responsabilidad, la transparencia, la capacidad de respuesta, el estado de derecho, la estabilidad, la equidad y la inclusión, el empoderamiento y la amplia participación (UNESCO).

Procesos ecológicos. Conjuntos de fenómenos e interacciones biofísicas que ocurren a nivel ecosistémico.

Resiliencia socio-ecológica. La resiliencia es la capacidad de un sistema, para enfrentar el cambio y continuar desarrollándose sin colapsar, sin cambiar a un estado no deseado, persistiendo, adaptándose o transformándose (modificado de Walker et al. 2012). La resiliencia socio-ecológica parte de la idea de que los seres humanos y la naturaleza están fuertemente acoplados, hasta el punto de que deben ser concebidos como un sistema socio-ecológico (Stockholm Resilience Centre 2015).

Servicios de los ecosistemas. Contribuciones directas e indirectas de la estructura y función de los ecosistemas -en combinación con otros inputs- al bienestar humano (Burkhard et al. 2012).

Sinergias de servicios de los ecosistemas. Una situación ganador-ganador, que implica una mutua mejoría entre dos servicios de los ecosistemas (Haase et al. 2012).

Suministro de servicios de los ecosistemas. Capacidad de un área particular de proveer un conjunto específico de servicios de los ecosistemas durante un periodo de tiempo definido (Burkhard et al. 2012).

Trade-offs de servicios de los ecosistemas. La forma en que un servicio ecosistémico responde a cambios en otro servicio (MA, 2005). Se considera que hay un trade-off entre servicios es aquella situación en que el suministro de un servicio determinado, o el valor de uno o varios servicios, compromete el suministro de otros servicios.

Tramas socio-ecológicas. Conjunto de interacciones dinámicas donde los fenómenos y procesos biofísicos y sociales están vinculados (Schmitz et al. 2018).

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ANEXO

ARTÍCULOS CIENTÍFICOS PUBLICADOS
QUE FORMAN PARTE DE ESTA TESIS

ARTÍCULO 01

Título: What do we talk about when we talk about Social-Ecological Systems? A literature review.

Autores: Cristina Herrero-Jáuregui, Cecilia Arnaiz-Schmitz, María Fernanda Reyes, Marta Telesnicki, Ignacio Agramonte, Marcos H. Easdale, María Fe Schmitz, Martín Aguiar, Antonio Gómez-Sal and Carlos Montes.

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Resumen:
En la última década, probablemente en respuesta a los cambios globales y la crisis ambiental, el uso del término "sistema socio-ecológico" (SES) en la literatura científica ha aumentado. Esto es una señal de que se ha reconocido la necesidad y la importancia de la investigación transdisciplinar. En este estudio, se explora si el término es una palabra de moda, o más bien, representa un concepto clave en la integración de la investigación social y ecológica. Para ello, se recopiló una base de datos de publicaciones (N = 1289) que mencionaban SES en el título, las palabras clave y el resumen. También, se analizaron las afiliaciones de los autores, el tipo de trabajo (conceptual, empírico o de revisión), el lugar de estudio, escalas espaciales y temporales del análisis, tipo de variables analizadas (socioeconómicas o biofísicas), y el método utilizados. Se detectaron cuatro períodos de tiempo en el uso del término (1975-1997, 1998-2006, 2007-2012, 2013-2016). Los resultados sugieren que el SES es un concepto ampliamente utilizado en el estudio de la interfaz entre los sistemas sociales y ecológicos. La mayoría de los trabajos muestran algunos elementos comunes, como el análisis de la resiliencia, los servicios de los ecosistemas, la sostenibilidad, la gobernanza y la gestión adaptativa. Sin embargo, la mayoría de los trabajos no estudian el SES integrando variables sociales y ecológicas y sus ciclos de retroalimentación. Consideramos SES como un concepto en construcción con el fin de elaborar un marco necesario para la integración de las ciencias sociales y ecológicas. Para una evolución sólida, recomendamos enfocarse en: (i) un esfuerzo consciente, discutido y acordado de los científicos para llevar a cabo la investigación transdisciplinaria necesaria para estudiar el SES; y (ii) el desarrollo de herramientas metodológicas para la verdadera integración de datos sociales y ecológicos.

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Review

What do We Talk about When We Talk about Social-Ecological Systems? A Literature Review

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Abstract: In the last decade, probably in response to global changes and the environmental crisis, the use of the term "social-ecological system" (SES) in scientific literature has grown. This is certainly a sign that the need and importance of transdisciplinary research has been recognized. Here, we explore whether the use of the term is a buzzword or, rather, actually represents a key concept in the integration of social and ecological research. We compiled a database of publications (N = 1289) that mentioned SES in the title, keywords and abstract. Subsequently, we analyzed the authors' affiliations, type of work (conceptual, empirical or review), study site, prevailing human use, temporal and spatial scales of the analysis, kind of variables analyzed (socioeconomic or biophysical), and the method/s used to integrate them. We detected four time spans in the use of the term (1975–1997, 1998–2006, 2007–2012, 2013–2016). Our results suggest that SES is a widely invoked concept in the study of the interface between social and ecological systems. Most works show some common elements, such as the analysis of resilience, ecosystem services, sustainability, governance and adaptive management. However, the majority of studies do not study SES as a whole, integrating both social and ecological variables and their feedback loops. We consider SES as a concept still in construction in order to build a necessary framework for the integration of social and ecological sciences. For a robust evolution, we recommend that one focus on: (i) A conscious, discussed and agreed effort of scientists to conduct the transdisciplinary research needed to study SES; and (ii) the development of methodological tools for the true integration of social and ecological data.

Keywords: adaptation; complex adaptative systems; ecosystem services; governance; resilience; sustainability; transdisciplinary

1. Introduction

The widespread and profound, wanted or unwanted, changes observed around the Earth have prompted the recognition that there is an urgent need to understand the ways in which humans affect and are affected by nature. It has become essential to work in the complex interface of ecological and social systems, which is where policies concerning land use are developed [1,2]. However, the fact that the proportion of pristine ecosystems is minor, and most of our ecological understanding derives from conservation areas, e.g., national parks, hinders true appreciation of the complexity of our living ground [3]. For example, managed or transformed ecosystems have lost large-size species, top predators, and many exotic species, which are common components of communities. There is indeed an increasing consensus that many of the complex world issues relating to the environmental crisis require management under the framework of sustainable development, as has been expressed in the Sustainable Development Goals (SDGs) [4]. Many aspects of the environmental crisis, considered at the launch of the Millennium Development Goals (2000), have been carried forward to SDGs because they are complex issues to be dealt within the social-ecological system (SES) framework. In turn, this involves integrating the social and natural sciences, and there is a growing agreement that transdisciplinary research is a key tool in facing environmental challenges. Hence, there is a need to expand the boundaries of the studied systems. These modifications mean shifting the object of study towards social-ecological systems [5–7].

The terms "socio-ecological system", "socio-ecosystem" and "social-ecological system" (henceforth, SES) are used synonymously and have emerged to address this complexity and integrate the social and ecological sciences. It is an anthropocentric concept, which appeared in the Anthropocene context of global change. The theoretical formalization of the concept has triggered research and literature into SES [4,8–14] (among others). Nowadays, these terms are widely used in environmental sciences. However, as with many other complex concepts associated with terms that have become fashionable buzzwords in the history of environmental sciences (e.g., biodiversity, resilience, governance, sustainability), there is a risk of these important concepts falling into confusion or banalization [15–17], emptying them of clear significance. The concept is not rigid [13] and there are different approaches and perspectives relating to the understanding of it [18,19], although it can also be used as a commonplace term because it is trending. In fact, several authors do not believe that there is a need for this new concept to be coined, as ecosystems already include social systems, since humans are part of nature [20].

Social-ecological systems, as complex adaptive systems, possess emergent properties [21,22], and resilience, or the system's ability to continue to function when intrinsic or extrinsic disturbances occur, is one of the most important [4,22]. SESs constitute co-evolving systems in which territorial and socioeconomic structures maintain constant and reciprocal interactions [4,6]. The biophysical-cultural coevolution in which agriculture has risen is a clear example of this. The emergent properties that are susceptible to identification and analysis depend on the social and ecological nature of the variables considered, their scale and the study methods used. However, cultural and ecological processes operate at different spatial and temporal scales, and it is thus difficult to find appropriate methodologies to measure and combine both types of variables at a meaningful and appropriate scale [23,24].

The aim of this systematic literature review is to analyze what has been considered and published under the term of SES since it first appeared. Specifically, the type of work where SESs are considered, where and by whom, under which kind of management, the type of variables analyzed, the temporal and spatial scales, and the methodology used. Drawing on the results, we address the main landmarks in the history of SES and discuss some major points derived from the analysis of the data, especially related to the asymmetries that might be identified. These potential unbalances refer to issues, such as theory vs. empirical evidence, biophysical vs. socioeconomic and cultural variables, agricultural intensification vs. urban expansion, and SES in developing countries vs. SES in developed countries. Based on the results, we elaborate some recommendations for the use of the term and the promotion of the concept. We believe the results of this review will be useful for defining the state of the art, identifying gaps in knowledge and addressing future research lines.

2. Methods

In December 2017, we conducted a review in Scopus, searching for the terms "socio-ecosystem", "social-ecological system", "socio-ecological system" and their Spanish translations, excluding those related to the areas of biomedicine, business, mathematics and physics, in the title, keywords and abstract. We used Scopus as the main database but also explored the trajectories of researchers and research groups using Google Scholar.

To detect the evolution of the use of the considered terms, referring to SES, we classified the number of published papers based on either biophysical or socioeconomic variables, independently, or on the combination of both types of variables. On the basis of this temporal classification, we performed multiple aggregation analyses of consecutive years, which were later validated by simple regression analyses, in order to detect discontinuities in the trend of the use of the term. The sets of selected years were those whose coefficient of determination (proportion of the variance 'explained' by the regression model) exceeded 70%. The statistical difference between the consecutive groups of years was performed using a mean comparison analysis (Fisher F-test; $k > 2$) that allowed us to characterize a qualitative variable (sets of years) by a quantitative variable (number of papers). From the stratified temporary database, we randomly selected a sample of 70% of the studies of each group of the years detected. Therefore, the final analyzed sample consisted of 990 papers. We deleted studies from 2017 because of the time-lagged response in the publication process.

In each study, we looked for information related to the characteristics of the publication, the importance given to the term, the management system studied, the scale of the analysis, the variables analyzed and the analytical procedures (Table 1). We assessed the importance given to the term by considering whether the authors defined the term and/or cited previous definitions. We built a data matrix that was analyzed by means of descriptive statistics, mainly including measures of frequency, using R 3.4.2 [25].

We characterized each country by its Gross National Income per capita (GNI, reported in U.S.$; https://data.worldbank.org/indicator) and used Social network analysis (SNA) to analyze the relationships between the funding country of the research (nodes; units of the network) and the country where the study area was located (edges, links or interactions between nodes, symbolized by arrows). The intensity of this relationship is represented by the thickness of the links, which mean the number of papers that share the same link (the two countries in relation, the financer and financed). The direction of the links indicates the direction of the financing (financing country at the beginning of the arrow, country financed at the end of the arrow). The size of each node corresponds to the total number of papers published by each country. When a country is both funder and funded, there is no a graphical representation of the link, and this situation is expressed by increasing the size of the corresponding node. These concepts are displayed in a social network diagram, where nodes are the points, and edges are the lines. We used the package network D3 from R [26].

Table 1. List of variables considered in each study and the corresponding attributes.

Variables	Attributes	Objectives
Publication characteristics		Description
Type of publication	Empirical, Theoretical, Modeling, Review	
Year of publication		
Organization of the first author	Origin in natural or social sciences	
Country's Gross National Income (2018)		
Subject area of publication	Environmental, biological or social sciences	
Importance given to the term		Assessing the importance given to the "social-ecological system" (SES) term
Location of the term	Title, abstract, keywords	
Definition of the term	Yes, no	

Table 1. *Cont.*

Variables	Attributes	Objectives
Characteristics of the system studied		
Location of the study area	Countries, places of study inside countries	
Country's Gross National Income (2018)		Social Network Analysis showing relationships between origin and site of study of publications
Main management/ focus of publication	Fishery, agriculture, conservation, cattle ranching, urbanization, forestry, tourism, agro-silvo-pastoral, hunting, restoration, mining	Description of the management system studied
Scale of analysis		Temporal and spatial scales at which the studies are conducted
Temporal scale	Days, months, years, centuries	
Spatial scale	Local, regional, global	
Variables analyzed		Type of variables mostly analysed
Biophysical	Climate variables, landscape, abiotic factors, census, samples/lab analyses	
Socioeconomic	Socioeconomic indicators, workshops, participant observation, interviews, previous surveys	
Analytical procedures		Methods used to combine different types of variables
Analysis of both biophysical and socioeconomic variables	Yes, no	
Methods used to combine both variables	Models, multivariate analysis, geographical information techniques	

3. Results

Based on the change in the slope of the linear fitting equations and the results of the mean comparison test, it was possible to differentiate four different time spans in the use of the term: 1975–1997, 1998–2006, 2007–2012, 2013–2016, with an increasing rate of published papers per year (Figure 1). The number of papers published in each period was significantly different from the number of papers published in the other periods identified (F-test, $p < 0.05$).

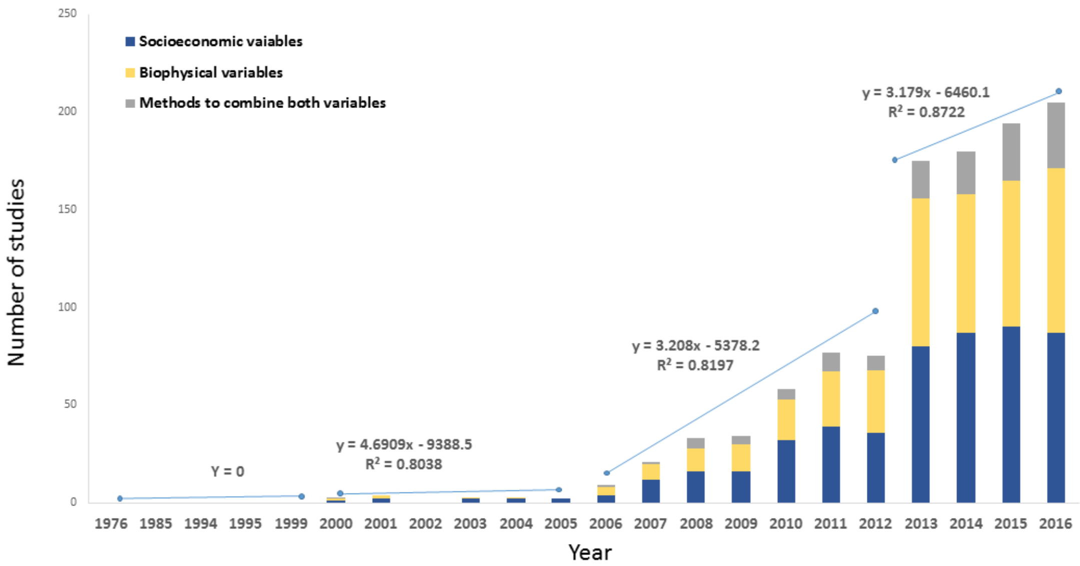

Figure 1. Evolution of analyzed publications containing the term "social-ecological system" (SES) in the title, abstract or keywords. Dashed lines adjust the different periods detected. The regression equation and the coefficient of determination (R^2) are shown. Blue and yellow colors indicate the number of publications that use either biophysical (blue) or socioeconomic (yellow) variables. In gray, the number of publications that use a mathematical method to integrate both types of variables.

Throughout these periods, a total of 1059 organizations were represented, although only a few of them could be considered as SES-specialists, having led, as the primary institution, at least five papers on this topic. For example, the Stockholm Resilience Center led, as the primary institution, 32 papers, followed by the Natural Resource Institute of Manitoba and the Arizona State University with 13 and 10 papers, respectively (Figure 2a).

The great majority of SES studies corresponded to research articles in the domain of environmental sciences (60%), followed by social sciences (25%) and agricultural and biological sciences (15%) (Figure 2b). Of these studies, 62% were conducted by researchers whose origin was in the natural sciences, while 30% had their origin in the social sciences.

The ten most frequently used keywords, associated with SES, were resilience, ecosystem services, sustainability, governance, adaptation, vulnerability, adaptive management, climate change, adaptive capacity and institutions (Figure 2c). Only 4% of publications mentioned SES in the keywords without studying it explicitly. With regard to defining the term, 16% of analyzed papers included a general definition of SES, whereas 29% cited someone as a reference for it. The most cited definition was the one proposed by Berkes and Folke [8].

Empirical studies were the most numerous (42%). These studies generated and analyzed the data of concrete study systems and were followed by conceptual papers (34%) and reviews or meta-analysis (21%) of different topics related to SES. Of the conceptual papers, 20% described some kind of model for the analysis of SES behavior in space and/or time (Figure 2d). The main spatial scale of analysis at which SESs were studied was local (53%), followed by regional (38%) and global (9%). Most temporal scales were in the range of 1–3 years, although there were several studies in the range of 30–100 years.

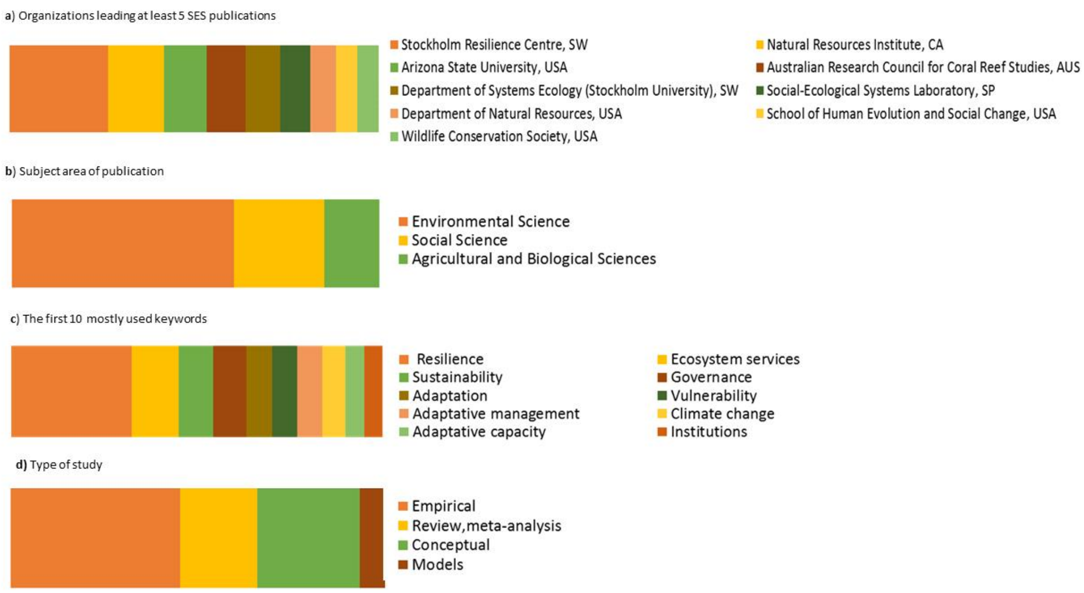

Figure 2. Percentage of studies belonging to different publication characteristic categories.

In empirical studies, the "type of management" most often analyzed related to productive activities, mainly fishing and agriculture (Figure 3a). The variables most frequently recorded in empirical studies were of the socioeconomic type (91%), almost doubling in importance studies that reported on biophysical variables (52%). In each type, variables from interviews at the local scale (32%, Figure 3b), as well as mapping and remote sensing analysis at the regional scale (36%, Figure 3c), were the most frequently reported. Only 43% of empirical studies gathered field data of both biophysical and socioeconomic variables, and half of these used some quantitative method to integrate both types of variables. The most frequent combining methods were mainly related to geographical information techniques, quantitative models, and multivariate analyses. The average inter-annual increase in the use of socioeconomic variables was 1.26 times higher than the increase in the use of biophysical ones and 2.58 times higher than the increase in methods integrating both types of variables (Figure 4).

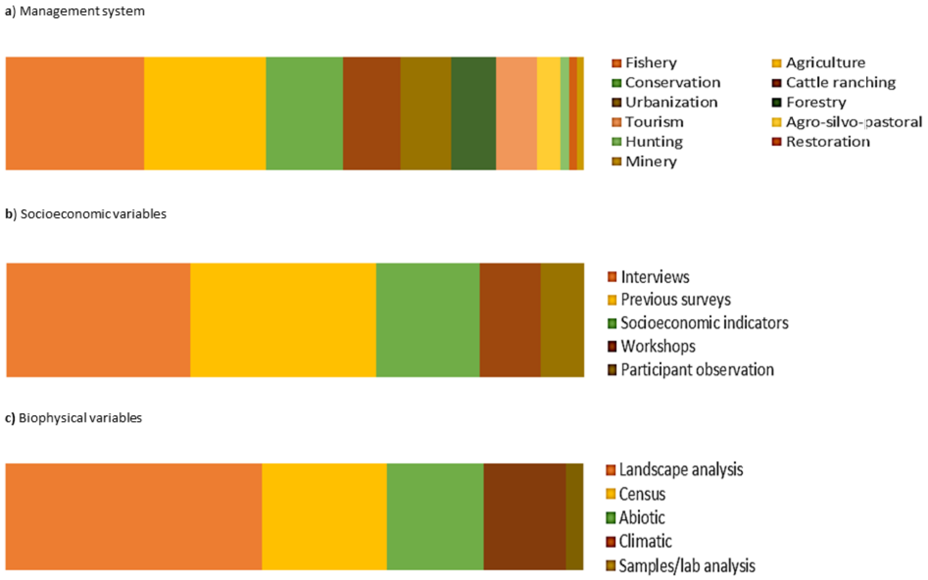

Figure 3. Characteristics of empirical studies addressing social-ecological systems (SES).

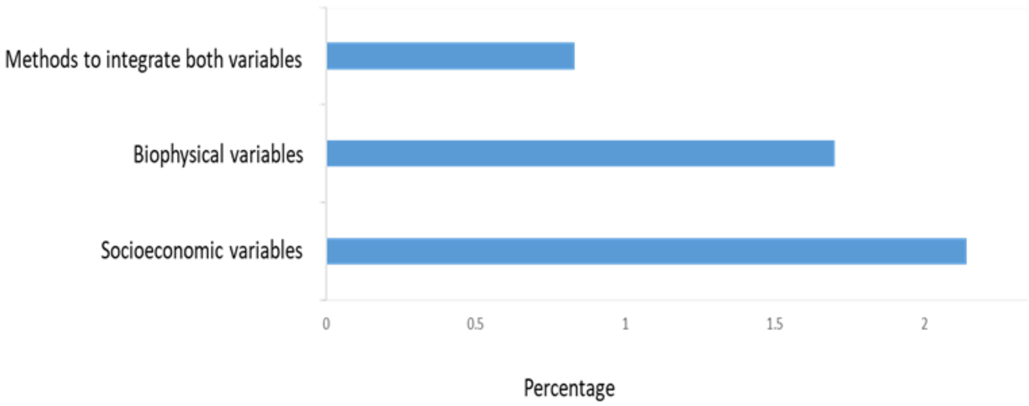

Figure 4. Average interannual variation of studies analyzing socioeconomic or biophysical variables or integrating both types of variables, in relation to the total number of papers reviewed each year between 1976 and 2016.

The majority (53%) of the empirical studies (i.e., developed in a determined study area) were financed and elaborated by countries of the so-called Global North (a term that denotes the generic geographic, historical, economic, educational, and political division between north and south). Moreover, 60% of these studies led by organizations of the Global North were conducted in countries of the Global South (as is expressed by the arrow direction between the nodes, shown in Figure 5).

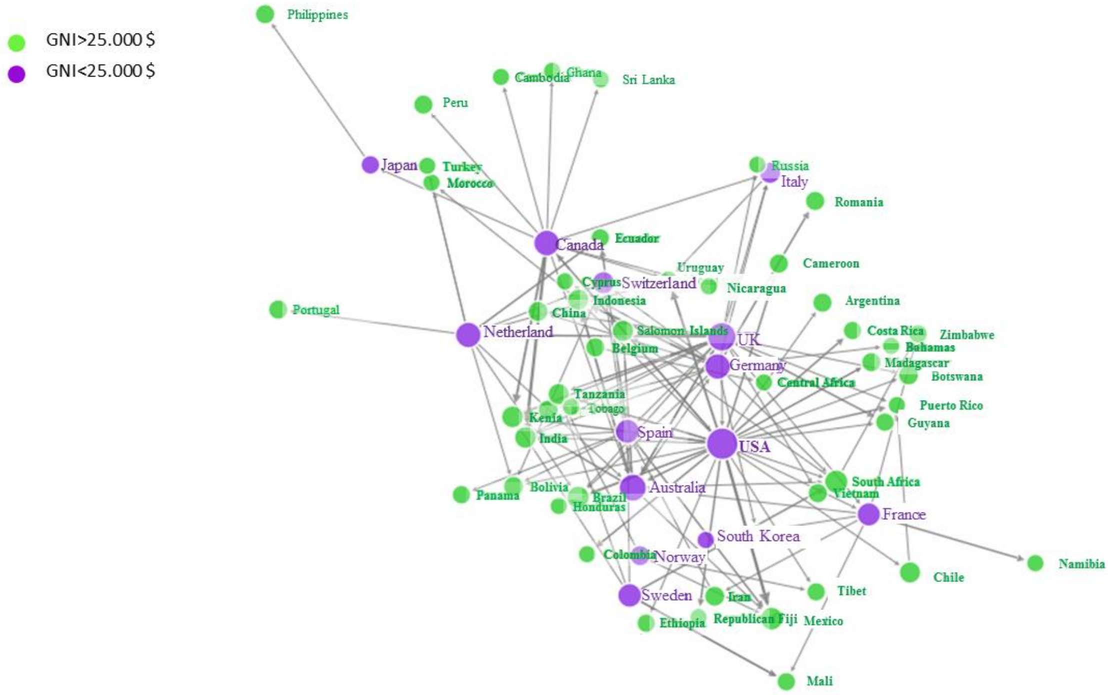

Figure 5. Social Network Analysis, showing the relationship between the funding country of the research (nodes) and the country where the study area is located (edges). The number of papers that share the same relationship is represented by the thickness of the links. Countries of the Global South (gross national income (GNI) < 25,000 U.S.$ per capita) are represented in green, and countries of the Global North (GNI > 25,000 U.S.$ per capita), in purple.

4. Discussion

4.1. Evolution of the Term

The temporal dynamics of the publication rate, at four different consecutive and overlapping phases (Figure 1), can be explained by some key works and actions. The term "social-ecological system" was first published by Crook et al. and Emory and Harris [27,28] in the context of animal behavior, and was followed by Goldberg, who studied some of the coping strategies of "human-centered socioecological systems" [29]. In this period, there was not a common understanding of what SES meant, but researchers used the term to refer to social-ecological relationships when they understood that what they intended to study was not included under the concept of ecosystem. Berkes and Folke started to use the concept of SES as an integrated approach of "humans-in-nature", linking it to the concept of resilience and emphasizing the biophysical limits of nature [8]. Concurrently, Simon Levin used Holland's concept of complex adaptive systems to describe SESs as non-hierarchical and dynamic systems [9]. The concept was further developed when Berkes and collaborators schematized its multi-scalar and nested properties [10]. This formalization of the term, and the foundation of the Resilience Alliance (RA) in 1999, probably triggered the "second phase" of SES history, from 1999–2006, during which the number of publications using SES, linking it to the concept of complex adaptive systems, started to grow (mean rate = 4.06).

In 2007, the Stockholm Resilience Centre (SRC) was funded, jointly embracing the concepts of resilience and SES [30]. Since then, the number of publications has grown at a faster rate (mean rate = 18.23) and used the term more consistently. In this phase, SESs were usually related to socio-ecological resilience, understood as "the capacity to adapt or transform in the face of change in social-ecological systems, particularly unexpected change, in ways that continue to support human well-being" [30]. Associated with the recently created SRC, Ostrom and collaborators proposed a general framework for the analysis of SES and defined the variables that were to be measured in each SES subsystem in order to study it [12]. Concurrently, Glaser and collaborators proposed a working definition for the concept of SES that included governance systems: "a social-ecological system consists of a bio-geo-physical unit and its associated social actors and institutions" [31]. In 2013, the SRC incorporated the term SES in the program of SDG, and this probably prompted the "fourth phase" (mean rate = 20.60) in the use of SES, from 2012 onwards, during which the number of publications significantly increased. In this fourth phase, the term was linked to governance systems, and it is noteworthy that the socioeconomic variables recorded were relatively more abundant than the biophysical ones (Figures 1 and 4). This is probably related to the fact that the majority of these publications focused on land management and decision-making.

4.2. The Matter of Socio-Ecological Systems: What, Who, How, and Where?

Half of all publications referred to empirical studies that generated and analyzed either primary data obtained in the field or secondary data. The rest of the publications were conceptual studies that did or did not propose a model and were based on reviews and descriptions. Empirical studies mostly incorporated socioeconomic variables through semi-structured interviews, particularly in the fourth phase (from 2012 onwards, Figure 4). This is probably related to the fact that the incorporation of SES to SDGs implied decision-making and management issues that were mostly accomplished using socioeconomic information. However, it is remarkable that these efforts, mostly published in journals of environmental sciences, were typically made by researchers from institutions linked since their origin to the natural sciences. This suggests a greater research motivation of natural scientists to study SES, which is not mirrored by institutions rooted in the social sciences. However, there is an implicit risk of researchers with insufficient background in the social sciences simplifying the social complexity of SES by incorporating just a few socioeconomic variables. Anyhow, this reflects an answer to the urgent need for change in the working system, from natural ecosystems to the interface of ecological and social systems [3,32] accompanying the emergence of the new science of sustainability [4].

However, ironically, parallel to this turn of natural scientists to working with socioeconomic data, there were comparatively few studies that analyzed biophysical variables, and the ones that did mostly based them on landscape and remote sensing analysis at regional scales. The study of SES is typically related to the study of ecosystem services; however, evidence suggests that the biophysical functions of ecosystem services are progressively being neglected. This result supports the need of incorporating biophysical information in the study of SES [33,34] and reflects the challenge of acquiring datasets measured at a fine resolution. Indeed, the spatial scale at which studies were conducted was mostly local, which was probably oriented toward the analysis of any specific kind of management, and, secondly, regional, which was mainly oriented toward governance studies. This evidence suggests that there is a gap between theoretical developments and empirical information that is able to effectively integrate social and biophysical data.

The different spatial and temporal scales at which sociological and ecological processes operate make it difficult to find appropriate methodologies to combine both types of variables at a meaningful scale and study SES in a way that aims to extract the emerging properties of the variables [24,35–37]. To avoid scale-driven mismatches between these different sources of data, and to generate sound inferences, data must be assembled into a single and comparable scale [38,39] (pp. 23–40), which is not a trivial challenge. In fact, although around 40% of empirical studies reported both biophysical and sociological variables, only the half tried to develop tools to integrate both sets of variables. These efforts were mainly accomplished using geographic information systems, multivariate analysis, and mathematical models, such as multiple regression analysis [6,40–42] or Bayesian networks [43–45]. Thus, there is room for developing SES studies by using analyses that combine both sets of variables at different spatial and temporal scales. Social-ecological network approaches are promising tools for social-ecological analysis [46]. Some applications include the role of social networks in natural resource management [47], the spatial organization of biological populations in fragmented landscapes [48], scale mismatches, and the value of social networks [49] and networks that consider ecological sites, which are interconnected by a mobile livelihood strategy, such as transhumant pastoralism [5]. Canonical correspondence analyses are also promising tools for jointly analyzing social and ecological structures, such as land cover, landscape configuration, and the socioeconomic characteristics of populations [7,50]. In a complementary fashion, it is important to develop a conceptual discussion among disciplines involved in the study of SES. Social research must engage in biophysical analysis as well as the reverse, embracing all the profundity and theoretical background of both the social and natural sciences.

Regarding the studied management system, most of studies referred, as expected, to productive activities, mainly fishing and agriculture. While agriculture is the human activity that occupies most of the land surface of the Earth, together with rangelands [3], fishing is the only productive activity, based on a wild resource, that implies such a volume of market and population. Additionally, fisheries tend to suffer from the tragedy of the commons at the national level [51]. Over-fishing alerts may be a geopolitical strategy for controlling fisheries in non-territorial waters, as risking such a resource would produce an enormous impact on societies and the economy on a global level. Therefore, it could have been this imminent risk and the catastrophic consequences for societies that triggered the joint study of societies and ecosystems under the term of social-ecological systems. In fact, it is in the coastal areas, where the experiences and theory of 'integrated management' encourage consideration of the variables of different disciplines, have had more development. Something similar has happened in "integrated watershed management" [52]. In contrast, despite the recognized importance of urban ecology and "novel ecosystems" [53,54], comparatively few studies on analyzed SES management activities typically related to urban or suburban areas, such as urbanization, tourism or waste production (but see [55–60]). Analysis of rural–urban gradients from an SES perspective is also an understudied but promising field [50]. Additionally, whereas warfare affects a large portion of ecosystems, often with profound changes [61], very few studies implicitly considered this factor in their analysis (but see [62]).

Finally, studies on SES are equally represented in countries with high and low GNI, contrary to what Martin et al. found when mapping where ecologist worked (Figure 5) [3]. This can reveal a hidden link between SES and rurality, traditional practices, conflictive socioeconomic scenarios and other issues related to developing countries. However, the fact that most of the studies conducted in the Global South came from organizations affiliated with the Global North means that they are dominated by northern research agendas, which do not necessarily address research questions of local interest that can help to solve social-ecological challenges [63,64]. Research practices must incorporate a clear awareness of the fact that theory and practice come from systems that are placed within some specific cultural context. This can help in moderating naive expectations concerning the policy impact of research results [65].

4.3. A Concept in Transition

Results from this study suggest that, on the whole, the term SES is not a buzzword, empty of significance. On the contrary, the concept is being progressively shaped using inputs from different key works on the matter, and nowadays, the majority of publications using this term explicitly study SESs, as explained in Section 4.2. Indeed, the fourth phase reflects what Folke describes as SESs for the sustainability of human well-being [30].

However, the lack of a common use of the term also reflects that the term "social-ecological system" is not yet a clearly defined concept, accepted by all scholars. Instead, it is still a concept under construction that is integrating many currents of thought, originated in different disciplines. Despite the lack of a general definition, results of this study show some common elements in most works dealing with SES. Such common elements, evidenced by shared keywords, are, among others, resilience, ecosystem services, sustainability, governance, adaptation, vulnerability, adaptive management and climate change. These standard elements can help to build a shared definition of SES. They mostly refer to systems' emergent properties and conceptualizations of key features aimed at fostering sustainability pathways. However, the frequency of keywords referring to social problems— such·as poverty, inequality, land grabbing, resource access conflicts, corruption, and even warfare—is comparatively smaller [66]. This situation may be due to the registered lack of participation of social scientists or to the dominant research interests highlighting resilience and adaptation as core properties for the future, rather than a critical position on current complementary social problems structuring social-ecological challenges.

Finally, the articulation of well-documented frameworks, can build bridges in terms of communication and language among scientific disciplines [67]. For example, frameworks that have originated in different research arenas, such as the state and transition model, rooted in the resilience approach and natural sciences [68], and the sustainable livelihoods approach, rooted in the vulnerability approach and social sciences [69], can provide a conceptual basis for theory and operative integration [70]. Similar examples are the search for a more integrated use of sustainability and resilience concepts in an environmental management context [71,72], as well as resilience and vulnerability [73].

4.4. *Recommendations for the Future*

Socio-ecological systems-oriented research has inspired advances in sustainability science and practice [10]. Based on results from this study, we identify six issues that we think need to be addressed in order to consolidate the study of SES throughout the world and foster progress towards sustainable development. They complement those priorities highlighted by Fischer et al. and insist on some observations made previously by other authors [33,34]:

1. A shared definition for "social-ecological system" would be desirable and would help to consolidate the concept in the context of the emerging science of sustainability.
2. Social scientists should collaborate with biophysical scientists as well as the reverse, to achieve a true transdisciplinary approach in the study of SES.
3. Biophysical data based on field sampling at meaningful scales must not be forgotten in the study of SES so that scientific foundations for ecosystem services can be provided.
4. Methods for the integration of social and biophysical data at a sufficiently fine resolution, which are likely to be comparable at different scales, must be developed.
5. More emphasis should be placed on the study of SES in management activities typical of urban and suburban areas, as well as the study of SES under warfare and social conflict scenarios.

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ARTÍCULO 02

Título: Modelling of socio-ecological connectivity. The rural-urban network in the surroundings of Madrid (Central Spain)

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Resumen:
A medida que la mayoría de los paisajes metropolitanos de Europa crecen, se produce un cambio en el entorno rural que los rodea. Entre las principales consecuencias de este proceso está la pérdida de los paisajes culturales tradicionales y cambios en la estructura socio-económica de las poblaciones locales. La falta de acoplamiento entre la "sociedad urbana y el campo" puede considerarse una fuerza impulsora de este proceso. El presente trabajo se centra en la red urbano-rural alrededor de la metrópoli de Madrid. Este trabajo desarrolla un modelo cuantitativo para explicar los vínculos socio-ecológicos rurales-urbanos, teniendo en cuenta la influencia de la metrópoli en la red de municipios vecinos. Los resultados muestran un gradiente de paisaje rural desde usos silvo-pastorales a usos agrícolas y mantiene diferentes interacciones con la socio-economía local. La polarización urbano-rural del territorio y el acceso a la metrópolis son los principales factores que influyen en la dinámica del paisaje. La cohesión territorial entre los municipios y la conectividad con la metrópoli son factores que determinan la estructura socio-ecológica. El área agrícola presenta una buena cohesión social, pero una conexión débil con la ciudad. El paisaje silvo-pastoral, por el contrario, mantiene fuertes vínculos con la metrópoli, pero una interconexión no significativa entre las ciudades pequeñas. El modelo probado constituye una herramienta útil para analizar la conectividad socio-ecológica y para cuantificar, diseñar y promover políticas de cohesión territorial.

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Modelling of socio-ecological connectivity. The rural-urban network in the surroundings of Madrid (Central Spain)

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Abstract
As most of Europe's metropolitan landscapes grow, a change is occurring in their surrounding rural environment. The consequences thereof mainly involve losses of traditional land uses and changes in the socioecomic structures of the local population. The lack of coupling 'urban society-countryside' can be considered to constitute a driving force of this process. The present paper focuses upon the rural-urban network around the metropolis of Madrid (Central Spain). We developed a quantitative model to explain the socio-ecological rural-urban linkages, taking into account the influence of the metropolis in the network of neighbouring municipalities. The results show a rural landscape gradient ranging from silvo-pastoral to agricultural land uses and maintaining different interactions with the local socioeconomy. Urban-rural polarisation of the territory and accessibility to the metropolis are the main factors influencing the landscape dynamics. Territorial cohesion among municipalities and connectivity with the metropolis are factors determining the socio-ecological structure. The agricultural area presents good social cohesion, but a weak connection with the City. The silvo-pastoral landscape, on the contrary, maintains prominent links with the metropolis, but a non-significant interconnection between the small towns. The model tested constitutes a useful tool for analysing socio-ecological connectivity and for quantifying, designing and promoting territorial cohesion policies.

Keywords Landscape–socioeconomy model · Metropolis · Rural-urban linkages · Small towns · Socio-ecological connectivity · Territorial cohesion

Introduction

Socio-political factors have historically influenced the cultural practices linking rural and urban societies, as well as the transformation of the territorial structure. In the last century, big cities have become large metropolitan areas around which a transformation usually occurs in the socioeconomic system, with

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consequences for the landscape structure (Gil-Alonso et al. 2016; Sohn and Reitel 2013). In Europe most metropolitan landscapes offer the image of a space clearly influenced by human activities, leaving almost no room for 'wild' landscapes or 'rural cultural' -in the way that these concepts are habitually understood (Forman and Godron 1986; McCloskey and Spalding 1989; Forman 2014; Müller et al. 2015)-. This circumstance is related to industrialisation, initially linked to the development of the city, and with a model of economic growth that has not always involved real development, since, in some cases, a considerable portion of increased gross national product (GNP) may have no relationship with real increases in goods and services (Haque 2004).

In recent decades, changes have been observed in the relationship between rural and metropolitan areas; these changes involve an increase in mobility and in the exchange of goods and information, greater economic delocalisation, specialization of land uses (production, tourism, residential,...) and greater complexity and emergence of social networks (Mitchell 2004; Castle et al. 2011). The dynamics of globalization, changes in production and in the socioeconomy, as well as processes of 'spatialization' (human occupation of the geographical space) and 'territorialisation' (appropriation of the natural environment by human societies), are having an increasingly greater effect on the rural-urban linkages and impact thereof upon the environment (Forman 2008, 2014; World Bank 2015). This can lead to the emergence of new forms of habitat, transformation of agricultural land for urban purposes and the creation of residential exurban spaces in rural areas, beyond a big city (Nassauer et al. 2004; Visscher et al. 2014). Indeed, new housing, relocation of economic activities and new communication and transport structures constitute the main changes in land uses resulting from rural-urban linkages (Mockrin et al. 2017; Weilenmann et al. 2017). Cities and small towns, whose structure and relative size have varied throughout recent history, are socio-ecological systems (Redman et al. 2004) and theircomplex interactions have always far surpassed the limits of the urban space, implying new relationships between the urban nucleus and the countryside. Thus, urban areas nowadays cover a wide functional space in which small towns and rural areas are included, with different socioeconomic, territorial and socio-ecological implications (Modica et al. 2012). The relevance of each population nucleus must therefore be considered in relation to the processes deriving from a system of conurbation (Barlow 1995).

This territorial model appears to be irreversible (Antrop 2000; EC 2006; Arnaiz-Schmitz et al. 2018). Nevertheless, some socioeconomic structures still allow the rurality of certain areas to be maintained, as well as their social cohesion, understood as the links between the members of a human rural community. The characteristics of these rural spaces depend to a large extent on factors such as physical distance and accessibility to the cities and metropolises, the type of investments and the availability of human capital (Vaishar and Zapletalová 2009; Forman 2014;). Socioeconomic characteristics are, in fact, key variables influencing the population dynamics of the rural areas and their landscapes (Geyer 2002). In addition, the sociological perspectives that consider rural places as a way of life (Antrop 2000; Gkartzios 2013) constitute a unique context of governance and land management that has particular consequences for rural-urban linkages and the resulting landscape.

These interactions refer to both the exchange of natural resources and the relationships between culture, socioeconomy and rural landscape (Schmitz et al. 2003; De Aranzabal et al. 2008). However, the socioeconomic characteristics of cities and of the rural environment have frequently been analysed as if they constituted independent systems, despite the intense development of transport and communications and of the almost universal interaction this implies. Moreover, rural lands and ecosystem functions are exploited intensely to provide ecosystem services to cities and new urbanized areas (Rees and Wackernagel 2008). Approaches that focus on the local socioeconomic framework are particularly needed to determine the dynamic pattern underlying complex socio-ecological systems (Ferrara et al. 2017).

The socioeconomic structure of the network of rural settlements is currently influenced by the metropolis. In this context, we can address several questions: What is the relationship between the socioeconomy and landscape of rural areas? Does relationship depend upon proximity to the metropolis? To what extent does the connection with the metropolis influence the degree of social cohesion in rural areas? How does this socio-ecological process affect the rural landscape? The present paper focuses on rural-urban relationships, considering the role of socio-ecological connectivity in shaping rural landscapes. It does so through the study of the Region of Madrid (Central Spain) as a representative of the situation in southern Europe, for which to date there has been scarce formal descriptions or numerical models of the ecological relationship between socioeconomic structures and landscape. The procedure followed involve *i)* establishing the relationship between the typology of the rural landscape and the socioeconomic characteristics of the network of small towns and other rural settlements, mainly villages and hamlets, surrounding a metropolitan system; *ii)* explaining the socio-ecological interdependence and the degree of cohesion within the rural-urban network and *iii)* formalising the socio-ecological links between the small town-rural settlement network and the metropolis.

Study area

The Madrid Region, in the central zone of the Iberian Peninsula (Fig. 1), is a characteristically continental Mediterranean environment (Di Castri and Mooney 1973; Blondel and Aronson 1995). This area, where altitude constitutes a major ecological factor (Acosta-Gallo et al. 2008; Rivas-Martínez 2011), consistsof three broad zones. About one third ofthe territory, situated in the W-NW area, comprises slopes and granitic mountain peaks. The remainder of the region, running in the S-SE direction, forms a rocky ramp or pediment, generally presenting a gentle slope; this is clearly separated by a fault from the remaining third of the territory, comprising a sand-clay sedimentary plain presenting very gently undulating surfaces.

The landscape, with the exception of the central metropolitan area and some relatively big towns, shows a predominantly rural cultural character (Schmitz et al. 2007a). The mountains exhibit well-differentiated altitudinal belts with Holm oak, Pyrenean oak, Scots pine forests and upland grasslands, silvo-pastoral uses, mainly with cattle, and urbanisation for secondary residences close to the permanently inhabited small towns in the low zones of the mountain slopes and pediment. The pediment landscape is characterised by silvo-pastoral uses (smaller forests than the above mentioned ones and *dehesa* with ash trees, Pyrenean oak or Holm oak, depending on the soil moisture; Joffre et al. 1999; Martín-Vicente and Fernández-Alés 2006) and with hardly any agriculture. Here there are also secondary residences. The sedimentary plain, criss-crossed with alluvial corridors converging towards the river Tagus, presents intensive –irrigated– and extensive agriculture (although in the Mediterranean territories entirely agricultural lands are not usually found; the habitual landscape consists of agro-pastoral uses, often with shrubs and pastures, scattered trees and hedgerows with woody species; Blondel and Aronson 1995; Schmitz et al. 2007b).

The towns are circumscribed into municipalities, which represent the local administrative units of the region (Fig. 1). The Madrid metropolis, located in the central part of this region, is a mixed network structure consisting of a 'model of transportation-corridors' between towns and of 'dispersed-sites' (Forman 2014), which gives rise to a very fuzzy boundary with the surrounding countryside. In the remaining part of the region there are approximately one hundred and fifty rural nuclei: 'small towns', with populations of around 6000 inhabitants, of a relatively similar size and whose municipalities cover over 45 km^2, and

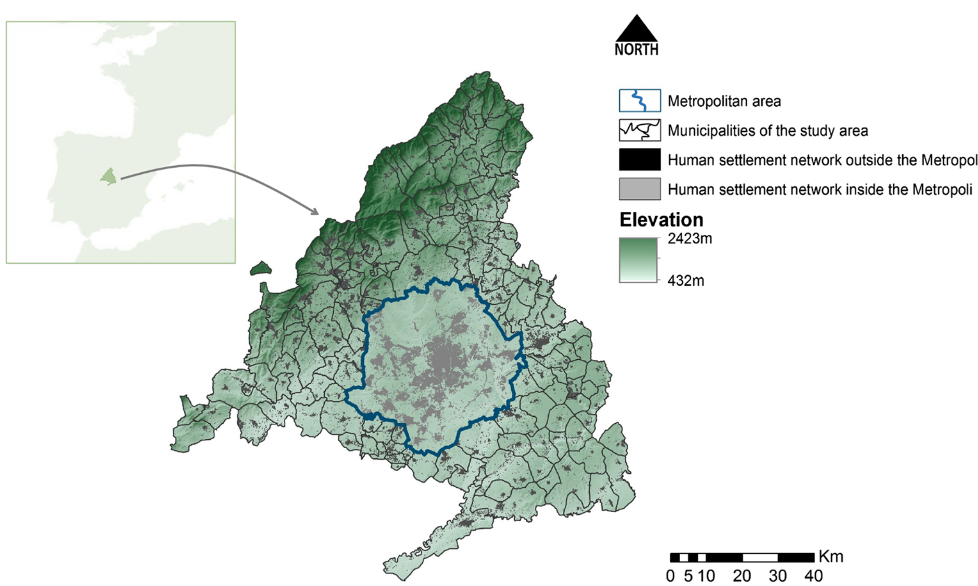

Fig. 1 Madrid Region, located in the centre of the Iberian Peninsula. The variation in altitude is indicated in green scale. The metropolitan area is located in the middle of the region and comprises the urban core (Madrid City) and its surrounding urban sectors, socioeconomically more directly tied to the City. All the urban areas are represented as grey nuclei. The boundaries of the municipalities are indicated. The municipalities can contain various small urban nuclei of different size, population density and degree of rurality (black shapes). See Appendix Table 5

other human settlements with less than 200 inhabitants and a municipal area averaging 22 km^2 (in Spain, municipal areas, delimited in the 19th and 20th centuries, present highly variable sizes).

Methods

We studied 157 municipalities excluding those closest to the city of Madrid, in order to avoid the above-mentioned diffused fringe, and considering only the most characteristic ones as being rural (Fig. 1). In each municipality we have considered two subsystems:

i) The rural landscape, analysed by means of a set of ecological descriptors that can be perceived through the land use/land cover and the landscape 'naturalness'. We used the concept of naturalness to describe gradients of human influence on the cultural landscape (Wrbka et al. 2004). Naturalness is a synthetic component of the landscape and was estimated by means of an index representing the degree of successional coincidence between the current vegetation and the potential one (i.e. the inverse of the successional distance between the two types of vegetation; see Foley et al. 2005; Rivas-Martínez 2011; Appendix Table 3). The index ranges, according to a rank of values, from 10 (natural plant communities) to 1 (urban areas). The naturalness value of each municipality was calculated considering the proportion of the different vegetation units in the municipal area.
ii) The set of urban nuclei, analyzed by means of socioeconomic variables, some of these descriptors of spatial interconnectivity among nuclei and between these and the City of Madrid (Appendix Table 4).

The 157 municipalities (Appendix Table 5) were used as analysis units. The information was obtained from available databases for the 1989 (t_1) - 2011 (t_2) period, referring both (i) to typology of the landscape: 31 landscape descriptors, according to the CAM (1997) and reviewed and validated through detailed field trips and (ii) to local socioeconomy: 29 variables according to the IECM (2016). Descriptors were quantified as the area occupied in relation to the area of the municipality. The value of the whole set of variables was expressed through their variation rate in the period considered $(t_2\text{-}t_1/t_1)$. Thus, we used two matrices of quantitative data describing the municipalities by means of the recorded landscape and the socioeconomic variables, respectively.

Firstly, we performed a multivariate ordination analysis (Principal Component Analysis, PCA) with the data matrix containing 157 municipalities × 31 landscape variables. The PCA is intended to identify directions (or principal components) along which the variation in the data is maximal (variation tendencies). The analysis provides factors or axes $Z_1,\ldots, Z_n$, each one of these describing a different underlying tendency of variation found in the initial dataset. Examination of the principal components set has enabled us to detect underlying trends and patterns that might otherwise be masked in a very large volume of data, or concealed by noise. This information is useful as it allows us to focus on highlighting and investigating only the limited amount of most important trends (percentage of variance explained for each principal component). The aim of this analysis involved detecting the spatial variation tendencies of the rural landscape, expressed by the main axes of the PCA, and identifying the key indicators of the landscape typology, according to the calculated loadings of the variables on each axis. In order to satisfy the analytical requirements of normality and homoscedasticity, we previously standardized and transformed the data by means of $log\ (x + 1)$, where x represents the value of each descriptive variable in each municipality.

Secondly, in order to explain the influence of the urban system upon the rural landscape, we applied a quantitative model similar to that followed by Schmitz et al. (2003, 2012) and De Aranzabal et al. (2008). This model enabled us to formalise the interdependence between the landscape structure and the variation of the socioeconomy in the study area. To this end, we considered the two main tendencies of spatial landscape variation, obtained by the PCA axes calculated. These two PCA axes were considered as dependent variables ($F_1$and F_2 respectively) of two regressions whose independent variables (s_i) were the variation rates of the 29 socioeconomic descriptors recorded in the small towns-rural settlement network, $F = f\ (s_i)$. Thus, F expresses the landscape typology detected and s_i, ($i = 1, 2, 3, \ldots 29$) represents the socioeconomic evolution. We calculated several regression functions to obtain the dependency equation that best fitted the available data: multiple linear, stepwise multiple linear, log-linear, stepwise log-linear and increasing degree polynomial. We used the Durbin-Watson test to verify the random variation of the residuals. All analyses were performed using the *XLStat* programme.

Results

Typology of landscapes

Figure 2 shows the PCA plane with the position of the municipalities according to the loadings of their landscape descriptors (Table 1). The municipalities are projected on the ordination plane in relation to the two main landscape variation tendencies, expressed by the first two PCA axes that together represent a large part of the total variability of the data (72.7% of variance absorption). Axis F_1 (variance 64.1%) indicates a 'silvo-pastoral–agricultural' variation in the municipalities as the main tendency of the rural landscape in the study area. Upland grasslands and broom shrublands at the top of the mountain (F_1loading − 11.27; Table 1) and reservoirs and urbanisations for second residences in the W-NW zone (F_1loading − 7.45) constitute the descriptors that most differ from those characterising the cultivated plain of the S-SE of the region (F1 loading 35.84).

Axis F_2 (variance of only 8.6%) indicates a 'silvo-pastoral' variability throughout the area comprising pediment and mountain. Riparian and Scots pine forests (F_2 loadings 3.22 and 2.02, respectively) indicate the landscapes of the upper slopes of the northern mountains, while Holm oak and juniper *dehesas* (F_2 loading −6.10), Mediterranean siliceous shrublands (−3.37) and urban areas (−2.00) represent the landscape of the pediment.

The distribution of the municipalities on the PCA plane indicates the homogeneity of the landscape in the agricultural area (right of the figure) in contrast with the 'silvo-pastoral' variation. Thus, along axis 1, from right to left of the figure, there is an increase in the scattering of the municipalities according to F_2 (dashed arrows). F_2 displays a lower polarity. The municipalities vary according to an altitudinal gradient along this axis. Naturalness is correlated with the position of municipalities along the two main axes, showing a higher value in the silvo-pastoral territory than in the agricultural lands (Fig. 2).

Figure 3 shows the spatial distribution of the municipalities studied according to the main tendencies of landscape variation detected (Fig. 3a_1) and the estimated naturalness (Fig. 3a_2).

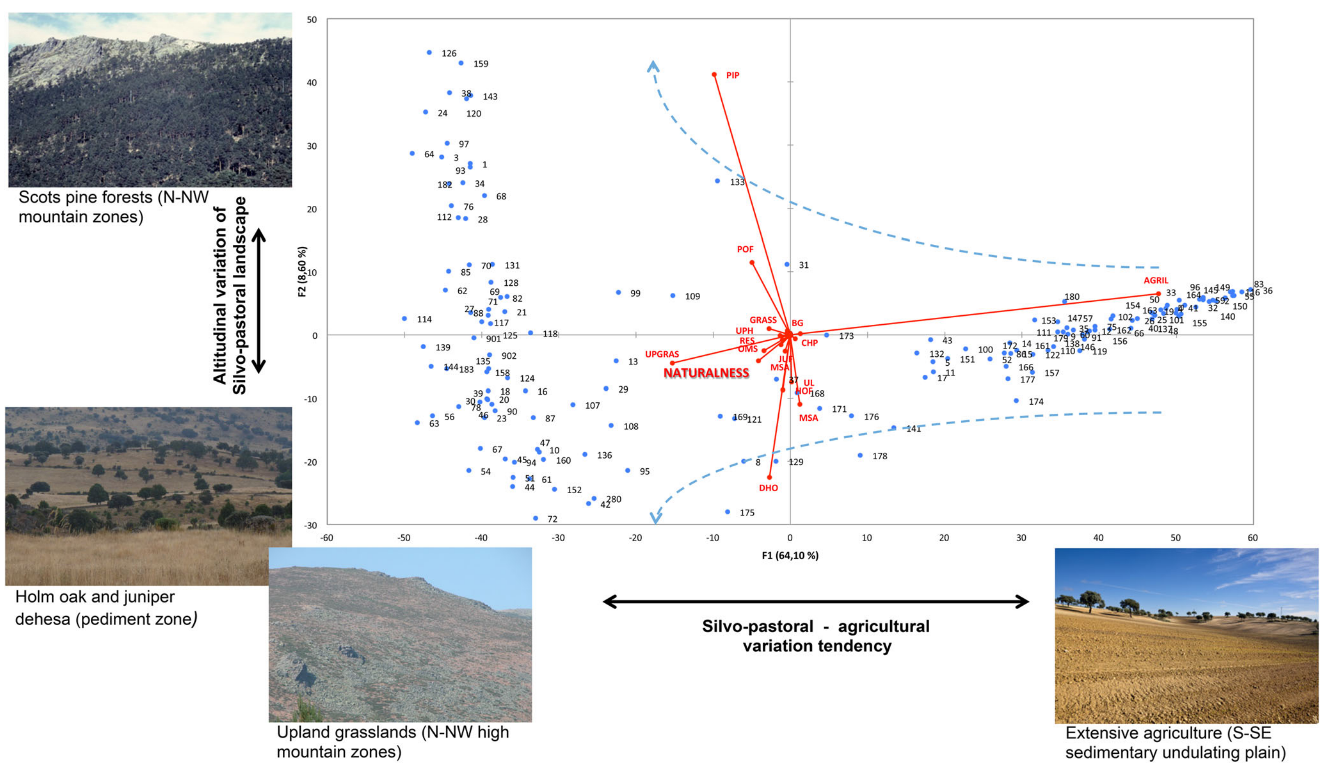

Fig. 2 Spatial variation in the rural landscape. Position of the municipalities on the PCA plane (codes in Appendix Table 5) according to the loadings of their landscape descriptors (Table 1). These are shown in red and are displayed on the plane according to their importance along the two axes. 'Naturalness' was considered as an external variable, not included in the analysis, but was then correlated with the two axes according to their value in the municipalities. The images of the ends of each axis show the types of landscape that better differentiate the study area. Dotted arrows indicate, from right to left in the figure (axis F1), the increasing scattering of the municipalities according to axis F2, indicating the landscape heterogeneity inside the silvo-pastoral zone

Table 1 Factor loadings of the vegetation and land use variables on the PCA plane

Code	Landscape variables	F_1 (64.10%)	F_2 (8.60%)
Agril	Agricultural lands	35.84	1.83
Asf	Ash forests	−1.01	−0.07
Bef	Beech forests	−0.02	0.01
Bg	Birch groves	0.00	0.01
Bra	Fern bushes	−0.01	0.02
Chp	Chestnut plantations	−0.09	0.05
Cof	Cork oak forests	−0.05	0.03
DCo	Pyrenean oak and Holm oak Oak dehesa	0.00	−0.01
DHo	Holm oak and juniper dehesa	−1.92	−6.10
Dlo	Ash trees-Lusitanian Pyrenean oak dehesa	0.03	0.00
Gras	Grasslands	−0.33	−1.42
Hel	Shrublands with heathers	−0.28	0.20
Hg	Holly groves	−0.03	0.07
Hof	Holm oak forests	−0.77	−2.48
Juf	Holm oak and juniper forests	−0.48	−0.63
Kos	Kermes oak and calcicolous shrublands	0.96	0.04
Lof	Lusitanian Pyrenean oak forests	0.05	−0.02
Msa	Mediterranean siliceous shrublands	0.81	−3.37
Of	Oak and Holm oak shrubs	−3.10	−0.85
Oms	Sparse Mediterranean oak scrubs	−0.94	−0.47
Pip	Scots pine forests	−0.04	2.02
Pof	Oak forests	−2.57	−0.79
Res	Reservoirs and second residence nuclei urbanisations	−7.45	−1.08
Rif	Mid-mountain riparian forests	−3.76	3.22
Rip	Riparian forests and poplar plantations	−0.80	−0.21
Rop	Rocky outcrops	0.46	−0.16
Ros	Rock-rose shrublands	−2.11	0.29
Ul	Villages and urbanized zones Urban and urbanised areas	0.27	−2.00
Upgras	Upland grasslands and broom shrublands	−11.27	0.05
Upsh	Midle and high mountain shrublands	−0.10	−0.09

The variables with greater weights, characterising the ends of the two axes, are indicated in bold. F_1 shows a much more marked variance absorption (in brackets) and polarity than F_2

Rural landscape-socioeconomy relationship

Among the set of regression functions calculated, the multiple linear regression models obtained better fits. Table 2 shows the two mathematical fit functions between the main landscape tendencies and their socioeconomic characteristics. Eight of the twenty-nine socioeconomic descriptors employed in the regression equations were the best indicators of the dependence between the silvo-pastoral-agricultural landscape tendency (PCA F_1) and the local socioeconomy (significance level > 95% for predicting landscape type; Table 2*a*). In the study period, the migration rate of the population (regression coefficient 0.88, Table 2*a*) is greater in the small towns of the agricultural zone, where there is also a relevant increase in the number of large holdings (>50 ha; coefficient 0.24) and the bus routes linking the small towns (coefficient 2.5). The opposite occurs with the bus routes linking the municipalities to Madrid City (coefficient − 4.63), although the distances to the city are generally not very great (coefficient − 1.57). The low number of intra-urban bus routes (coefficient − 3.94) and the low electricity consumption per capita of these nuclei (coefficient − 2.96) are characteristics of the small agricultural towns on the S-SE plain, as opposed to the municipalities of the W-NW zone.

As regards the altitudinal variation in the silvo-pastoral landscape (PCA F_2; Table 2*b*), seven socioeconomic indicators explain the typology of the rural

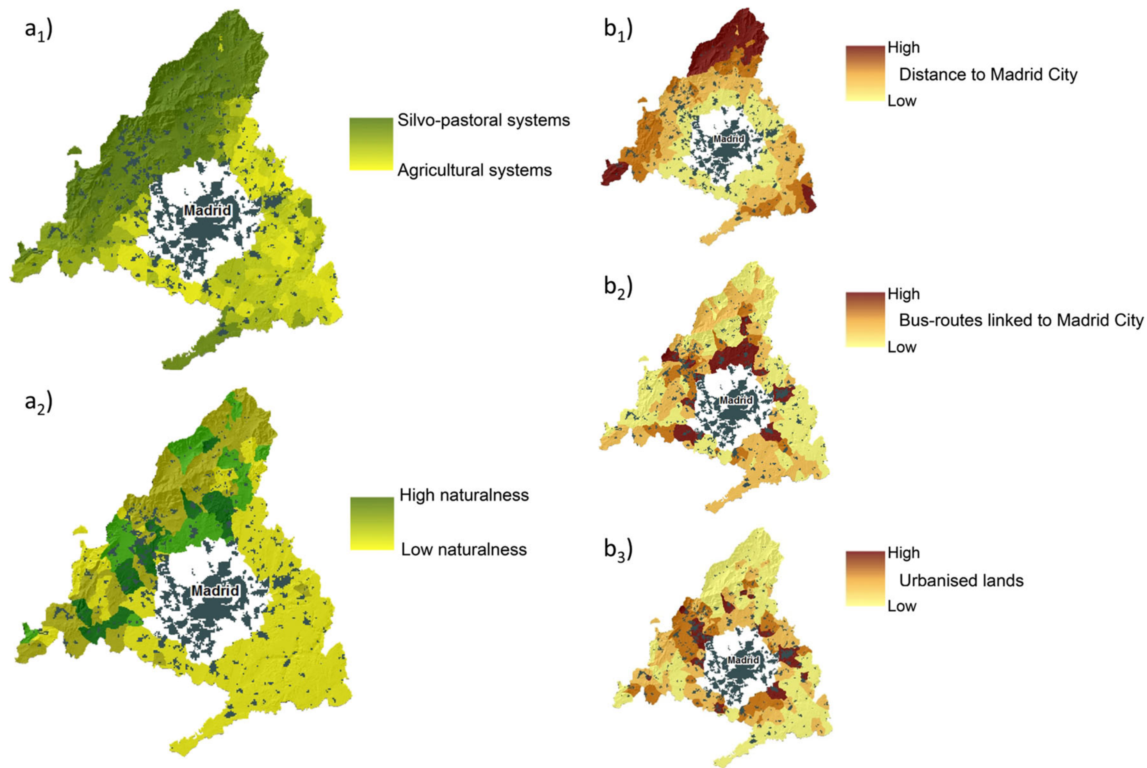

Fig. 3 Mapping the municipalities studied according to (**a**) the landscape types detected and the estimated 'naturalness'; **b** some relevant socioeconomic characteristics

landscape (significance level ≥ 95%). In this case, distance to Madrid City (regression coefficient 0.85), intra-urban bus routes (coefficient 0.65) and number of private cars (coefficient 0.32) are positively related with the landscape of the municipalities located in the higher altitudinal areas. On the other hand, the bus routes leading to Madrid City (regression coefficient − 1.79) and the sale of bus tickets (regression coefficient − 4.90) are descriptors of mobility characterising the municipalities presenting small- and medium-sized holdings (regression coefficients −4.54 and − 4.24, respectively) located on the border of the mountains and the pediment.

Table 2 Multiple linear regression functions showing the dependence between the main landscape tendencies of variation (axes F_1 and F_2 of the PCA plane, Fig. 2) and the socioeconomic characteristics of the municipalities considered in the analysis

a) Variation between the silvo-pastoral landscape and the agricultural landscape
F_1 = 83.66 + 0.884 Migration rate + 0.239 Large holdings (≥50 ha) – 0.39 Horse farms – 2.96 Electricity consumption per capita – 1.57 Distance to Madrid city – 4.63 Bus routes linking to Madrid city +2.51 Bus routes linking to other small towns – 3.94 Intra-urban bus routes
b) Altitudinal variation of silvo-pastoral landscape
F_2 = 1.04–4.54 Small holdings (< 20 ha) – 4.24 Medium holdings (20–50 ha) – 4.90 Points of sale for bus tickets +0.32 Total private cars +0.849 Distance to Madrid city – 1.79 Bus routes linking to Madrid city +0.65 Intra-urban bus routes

Number of municipalities: 157; Number of socioeconomic variables: 29; F_1 regression: R^2 = 0.59; DW: 1.98; F_2 regression: R^2 = 0.33; DW: 2.15. Only significant variables (p > 95%) are shown

Figures 3b$_{1,2}$ map the spatial distribution of two of the main indicators detected in the regression models, which link the territorial structure of the region with the possibilities for connection with Madrid City. Considering urban development as an external variable of the calculated dependence models (Fig. 3b$_3$), a spatial pattern can be observed that is closely related to the detected indicators of municipal connectivity with the metropolitan area.

Discussion

Altitudinal and geomorphological variation constitute the major environmental factors determining the landscape structure in the study area. Associated with these factors, socioeconomy outlines the characteristics of the current vegetation and land use, resulting in a rural cultural landscape that is generally expressed as a 'silvo-pastoral – agricultural' spatial variation (Fig. 2).

The naturalness or ecological integrity (Krosby et al. 2015) of the landscape typologies displays a higher value in the silvo-pastoral territory (Figs. 2 and 3a_2), including pasture and *dehesa*systems, whose traditional landscape maintains the highest values of plant diversity registered in Spain (5 *bits*, Pineda et al. 1981). As estimated here, this greater naturalness is close to the current state of the upland grasslands and broom shrublands, Scots pine and oak forests of the W-NW zone. However, grasslands are actually pastures that are traditionally consumed during the summer by transhumant cattle; furthermore, the selective logging is periodically performed in the pine and oak forests and the understory is also cleaned. Thus, the natural resources in the study area have traditionally been used and modified by humans, and their landscape therefore cannot be considered as natural, although it is often perceived and valued as exhibiting a high degree of naturalness (Lamb and Purcell 1990). Even further removed from a state of naturalness is the S-SE agricultural plain, which likely does not resemble the natural landscape that existed in the remote past -it currently constitutes a clearly cultural and notably homogeneous one. In any case, one must consider that there are no social systems without any nature or ecosystems without people (Petrosillo et al. 2015).

The set of small towns studied show a different behaviour pattern throughout the landscape variation described. Some authors consider that the small towns and villages condition the characteristics of the surrounding rural landscape, but that they also are dependent upon certain socioeconomic variables conditioned by the big metropolis (Frey and Zimmer 2001; Paddison 2001; Antrop 2004). In the area and period considered, these processes occur in varying degrees (Table 2). Thus, the migration rate is greater in the agricultural area, while its interconnection with Madrid City is weak (few bus routes). In this zone, the few intra-urban bus connections and low level of electricity consumption are remarkable. This is a peculiarity of rural localities which have a weak link with the big city, but which maintain a good degree of social cohesion, indicated by the bus routes linking small towns (Beckley 1994). The economy in these agricultural areas mainly involves the exploitation of large holdings. These socio-economic processes do not occur in the small towns spread throughout the W-NW silvo-pastoral zone, where the estimated naturalness is higher and the economy is associated with small- and medium-sized holdings. As opposed to the agricultural land, these small towns exhibit high levels of energy consumption, more private cars and better connection with the City than the agricultural area; the interconnection among neighbouring towns is not significant, indicating in this case low territorial cohesion (with its implicit social dimension) and strong dependence on the metropolis. Social cohesion is highest when local people work together to achieve some self-defined economic, social, political, or cultural objectives (EPRC 2010). In any case, improved accessibility and communications among the different rural areas and between these and the City have contributed to shaping an urban model that is spreading throughout the territory, generating zones of conflict that diffuse the boundaries between countryside and metropolitan area (EC 2006) and do not facilitate cohesion as a system. This may imply that territorial cohesion can be built at different scales and that cohesion on one scale does not necessarily build cohesion on another. These results are useful for designing and implementing policies intended to promote cohesion.

Although territorial cohesion is central to the European Cohesion Policy (EC 2014), and rural-urban linkages constitute a component of Europe's territorial cohesiveness, distance from, and accessibility to, the metropolis are determining factors of the structure studied (Dupy 1995; Antrop 2006; García-Delgado 2007; Vaishar and Zapletalová 2009). Thus, connectivity with the City, expressed differently at the ends of the gradient described, is relevant with regard to explaining the 'urban nucleus-landscape' interdependence of all the small towns in the region studied (Fig. 3b_1; see Healey 2002). Different authors state that the social networks between small towns is almost nonexistent and unrelated to the current rural landscape (Mitchell 2004; Castle et al. 2011), whilst the structures of transport and commuting between small towns and the metropolis does play an influential role (Fig. 3b_2; see Geyer 2002). Socioeconomic factors involving development and improvements in multimedia connectivity, education, labour, and transportation are important for the growth of rural territories, but transport in particular makes living and working in rural areas easier (Hansen et al. 2002; Levitt 2002). Thus, urban-rural polarisation of the territory and accessibility are the main factors influencing the landscape dynamics (Antrop 2006).

The European Spatial Development Perspective (CEC 1999) proposes polycentric development to counteract spatial imbalances. In the study area, the economic and land planning models have not been developed in accordance with the rationale of the EU cohesion policy, which establishes that people should not be disadvantaged by their place of residence and work (Faludi 2006). The importance of connectivity with the metropolis and the internal cohesion of the territory are related to urbanisation dynamics. In particular, urbanisation processes and their associated transportation infrastructures define the relationship between city and countryside (Antrop 2004). In the mid-1990s, suburbanization and metropolitan expansion were the two main characteristics of the Spanish urban system, which led to rapid expansion of the urban peripheries (Gil-Alonso et al. 2016). Madrid maintained a concentric-rings model up to the 1960s and currently presents a dispersed pattern favoured by the development of transport infrastructures, such transport corridors connecting the metropolitan area with small towns and other dispersed settlements (Forman 2014).

The urban development of the W zone and periphery of the metropolis can be interpreted as resulting from intense and speculative relocation of activities of the service sector, associated with the urban intensification and sprawl (Fig. 3b_3). However, 88% of the nuclei does not reach 50,000 inhabitants and concentrates 15% of the population of the region, whereas 55% has less than 5000 inhabitants and barely totals 2% of the population (IECM 2016).

In Europe, many rural territories that are disconnected from metropolitan systems have barely undergone any changes in their traditional economic activities, which continue to be closely related to the demands of the European Union Common Agricultural Policy; despite this, an evident process of depopulation and abandonment is occurring (Barbero-Sierra et al. 2013). This is the case in the above mentioned S-SE zone in Madrid. Spain's inland depopulated and marginalised areas are similar to those of other central and southern European countries (Agnoletti 2014).

According to a model of metropolitan-rural influences, one must consider that economic development does not only entail growth, and that the territory-resource and territory-problem relationships need to be considered. The urban–rural dichotomy along the detected landscape gradient can be understood as a displacement of the degree of human influence from rural to urban landscapes, including socio-ecological processes, flows of energy, goods, services, people, capital, and information (Modica et al. 2012). However, few relevant studies in Spain address territorial dynamics considering connectivity (either biological or movement of people and goods and communications; Rosell et al. 2003; Pineda and Schmitz 2011), mobility between places of residence and work (Serra et al. 2014) or the ecological effects of different urbanisation trends (Redman et al. 2004; Shuqing et al. 2006; Xun et al. 2017).

Conclusion

The structure of a rural cultural landscape can be related to the socioeconomy of its population settlements through quantitative models presenting different degrees of complexity. We have developed a simple model, based on multiple linear regressions, which fits the socio-ecological information considered. The model shows a landscape gradient showing a clear differentiation of the rural landscape of the municipalities according to their current land uses, either silvo-pastoral or agricultural. In both cases, the distance and accessibility of the small rural towns from the metropolis are determining factors of the socio-ecological structure, as are the different degrees of territorial cohesion among the municipalities along the land use gradient. The settlements in the agricultural area show good social cohesion, but poor connection with the City. On the contrary, there is no significant interconnection between the small towns of the silvo-pastoral landscape, which nevertheless maintain close ties with the metropolis.

The gradient of rural landscapes presenting different types of land use intensities, the reciprocal interactions between landscape typology and socioeconomic structure of local populations, as well as their functional relationship with the metropolis, have hardly been considered in the literature, despite their importance for the socio-ecological diagnosis of a landscape. The method applied stands out as a useful numerical tool for detecting the relationship between two complex structures (landscape and socioeconomy); it should also be considered useful for improving environmental management schemes and socio-ecological land planning, for characterising the role of socio-ecological connectivity, and for designing and promoting cohesion policies enabling citizens to take full advantage of the inherent features of the territories in which they live.

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Appendix 1

Table 3 Vegetation and land use which have been used as descriptors of the rural landscape typologies in each municipality (CAM, 1997)

Code	Landscape descriptors	Code	Landscape descriptors
Agril	Extensive agricultural lands(2)	Lof	Lusitanian oak forests(8)
Asf	Ash forests(8)	Nat	'Naturalness' of the landscape*
Bef	Beech forests(8)	Msa	Mediterranean siliceous shrublands(5)
Bg	Birch groves(7)	Of	Oak and Holm oak shrubs(4)
Bra	Fern bushes(5)	Oms	Sparse mediterranean oak scrubs(4)
Chp	Chestnut plantations(4)	Pip	Scots pine forests(8)
Cof	Cork oak groves(5)	Pof	Oak forests(8)
DCo	Oak dehesa(7)	Res	Reservoirs and second residence nuclei(3)
DHo	Holm oak and juniper dehesa(7)	Rif	Mid-mountain riparian forests(8)
Dlo	Ash trees and Lusitanian oak dehesa(7)	Rip	Riparian forests and poplar plantations(4)
Gras	Grasslands(5)	Rop	Rocky outcrops(7)
Hel	Shrublands with heathers(7)	Ros	Rock-rose scrublands(4)
Hg	Holly groves(7)	Ul	Villages and urbanized zones(1)
Hof	Holm oak forests(8)	Upgras	Upland grasslands and broom shrublands(9)
Juf	Holm oak and juniper forests(8)	Upsh	Midle and high mountain shrublands(8)
Kos	Kermes oak and calcicolous shrublands(7)		

The descriptors were measured by the percentage of their area within the municipal area. An asterisk indicates the 'naturalness' of the landscape, estimated with the use of an ordinal scale (small numbers in brackets) and considering the proportion of the vegetation units and land use types in the municipal area. The estimated values are the inverse of the successional distance between the current vegetation and the potential one (Rivas-Martínez 2011). It was applied in the study area from 10 (natural plant communities) to 1 (urban, buildings)

Appendix 2

Table 4 Variation rate of the socioeconomic variables measured in each municipality from 1989 to 2009. Official database codes are indicated in brackets (IECM 2016)

Variables	Units	Variables	Units
Annual work unit (AWU) of agricultural holdings (S_{18})	Variation rate	Pig farms (S_{17})	Variation rate
Bus routes linking to Madrid city (S_{25})*	Number	Points of sale for bus tickets (S_{28})*	Number
Bus routes linking to other small towns (S_{26})*	Number	Population growth density (S_1)	Inhabitants/km^2
Bus shelters (S_{22})	Variation rate	Poultry farms (S_{12})	Variation rate
Cadastre rural values per rural area (S_8)	Variation rate	Public buses (S_4)	Variation rate
Cadastre value per urban unit. Estate cadastre (S_6)	Variation rate	Regular bus routes (S_{21})	Variation rate
Cattle farms (S_{13})	Variation rate	Sheep farms (S_{16})	Variation rate
Distance to Madrid city (S24)	Kilometers	Small holdings (less than 20 ha) (S_9)	Variation rate
Electricity consumption per capita (S_{19})	Variation rate	Taxis (S_5)	Variation rate
Goat farms (S_{14})	Variation rate	Total passenger and commodity vehicles (S_{20})	Variation rate
Horse farms (S15)	Variation rate	Total private cars (S_3)	Variation rate
Intra-urban bus routes (S_{27})*	Number	Total rural area percentage. Estate cadastre (S_7)	Variation rate
Large holdings (50 ha and more) (S_{11})	Variation rate	Train stations (S_{23})	Variation rate
Medium holdings (from 20 to 50 ha) (S_{10})	Variation rate	Water consumption per capita (S_2)	Variation rate
Migration rate (S_{29})	Variation rate		

An asterisk indicates variables measured only in 2009, according to data availability

Appendix 3

Table 5 Relation of 157 municipalities in the rural surroundings of the metropolis of Madrid and their official database codes (IECM 2016)

Name	Code	Name	Code
Acebeda	1	Cubas	50
Ajalvir	2	Daganzo de Arriba	53
Alameda del Valle	3	Escorial	54
Alamo	4	Estremera	55
Alcala de Henares	5	Fresnedillas de La Oliva	56
Aldea del Fresno	8	Fresno de Torote	57
Algete	9	Fuente El Saz de Jarama	59
Alpedrete	10	Fuentidueña de Tajo	60
Ambite	11	Galapagar	61
Anchuelo	12	Garganta de Los Montes	62
Aranjuez	13	Gargantilla del Lozoya	63
Arganda	14	Gascones	64
Arroyomolinos	15	Griñón	66
Atazar	16	Guadalix de La Sierra	67
Batres	17	Guadarrama	68
Becerril de La Sierra	18	Hiruela	69
Belmonte de Tajo	19	Horcajo de La Sierra	70
Berrueco	20	Horcajuelo de La Sierra	71
Berzosa del Lozoya	21	Hoyo de Manzanares	72
Boalo	23	Humanes de Madrid	73
Braojos	24	Loeches	75
Brea de Tajo	25	Lozoya	76
Brunete	26	Lozoyuela-Navas-Sieteiglesias	901
Buitrago del Lozoya	27	Madarcos	78
Bustarviejo	28	Manzanares El Real	82
Cabanillas de La Sierra	29	Meco	83
Cabrera	30	Miraflores de La Sierra	85
Cadalso de Los Vidrios	31	Molar	86
Camarma de Esteruelas	32	Molinos	87
Campo Real	33	Montejo de La Sierra	88
Canencia	34	Moraleja de Enmedio	89
Carabaña	35	Moralzarzal	90
Casarrubuelos	36	Morata de Tajuña	91
Cenicientos	37	Navacerrada	93
Cercedilla	38	Navalafuente	94
Cervera de Buitrago	39	Navalagamella	95
Chapineria	51	Navalcarnero	96
Chinchon	52	Navarredonda y San Mames	97
Ciempozuelos	40	Navas del Rey	99
Cobeña	41	Nuevo Baztan	100
Collado Mediano	46	Olmeda de Las Fuentes	101
Collado Villalba	47	Orusco de Tajuña	102
Colmenar de Oreja	43	Patones	107
Colmenar del Arroyo	42	Pedrezuela	108
Colmenar Viejo	45	Pelayos de La Presa	109
Colmenarejo	44	Perales de Tajuña	110

Table 5 (continued)

Name	Code	Name	Code
Corpa	48	Pezuela de Las Torres	111
Pinilla del Valle	112	Torremocha de Jarama	153
Piñuecar-Gandullas	114	Torres de La Alameda	154
Pozuelo del Rey	116	Valdaracete	155
Pradena del Rincon	117	Valdeavero	156
Puebla de La Sierra	118	Valdelaguna	157
Puentes Viejas	902	Valdemanco	158
Quijorna	119	Valdemaqueda	159
Rascafria	120	Valdemorillo	160
Redueña	121	Valdemoro	161
Ribatejada	122	Valdeolmos-Alalpardo	162
Robledillo de La Jara	124	Valdepielagos	163
Robledo de Chavela	125	Valdetorres de Jarama	164
Robregordo	126	Valdilecha	165
Rozas de Puerto Real	128	Valverde de Alcala	166
San Agustin de Guadalix	129	Vellon (El)	168
San Lorenzo de El Escorial	131	Venturada	169
San Martin de La Vega	132	Villa del Prado	171
San Martin de Valdeiglesias	133	Villaconejos	170
Santa Maria de La Alameda	135	Villalbilla	172
Santorcaz	137	Villamanrique de Tajo	173
Santos de La Humosa	138	Villamanta	174
Serna del Monte	139	Villamantilla	175
Serranillos del Valle	140	Villanueva de La Cañada	176
Sevilla La Nueva	141	Villanueva de Perales	178
Somosierra	143	Villanueva del Pardillo	177
Soto del Real	144	Villar del Olmo	179
Talamanca de Jarama	145	Villarejo de Salvanes	180
Tielmes	146	Villavieja del Lozoya	182
Titulcia	147	Zarzalejo	183
Torrejon de La Calzada	149		
Torrejon de Velasco	150		
Torrejon del Rey-Guadalajara	280		
Torrelaguna	151		
Torrelodones	152		

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ARTÍCULO 03

Título: Identifying socio-ecological networks in rural-urban gradients: Diagnosis of a changing cultural landscape

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Resumen:
Los sistemas socio-ecológicos mantienen interacciones recíprocas entre las estructuras biofísicas y socioeconómicas. Como resultado de estas interacciones, surgen servicios esenciales para la sociedad. La expansión urbana es un impulsor directo de los cambios en los usos del suelo y causa cambios importantes en las relaciones socio-ecológicas y los estilos de vida asociados. El marco de los gradientes rural-urbanos ha demostrado ser una poderosa herramienta para la investigación ecológica sobre las influencias urbanas en los ecosistemas y sobre cuestiones sociológicas relacionadas con el bienestar social. Sin embargo, hasta la fecha no se ha intentado obtener una clasificación de municipios en gradientes rural-urbanos basada en interacciones socio-ecológicas. En este trabajo, desarrollamos un enfoque metodológico or su grado de acoplamiento biofísico y socioeconómico y diferentes indicadores de la estructura del paisaje y el bienestar social. Proponemos el modelo desarrollado como una herramienta útil para mejorar los esquemas de gestión ambiental y planificación del territorio desde una perspectiva socio-ecológica, especialmente en territorios sujetos a transformaciones urbanas intensas y pérdida de la ruralidad.

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Identifying socio-ecological networks in rural-urban gradients: Diagnosis of a changing cultural landscape

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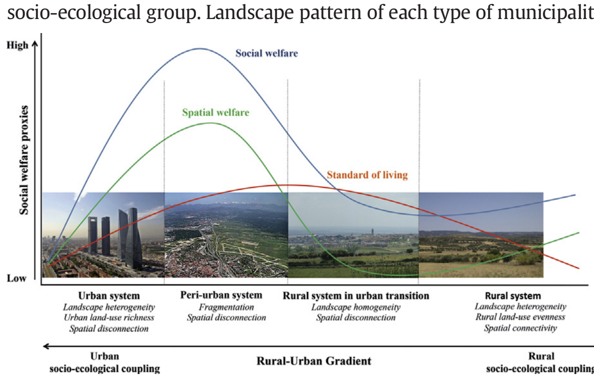
HIGHLIGHTS

- We used a method that detects socio-ecological networks in rural-urban gradients.
- The method links socio-ecological types with spatial patterns and social welfare.
- Our model highlights the coupling between landscape and socioeconomic structures.
- The results detect municipality types along a rural-urban gradient in Madrid Region.
- The proposed model can improve land planning from a socio-ecological perspective.

GRAPHICAL ABSTRACT

Graphic scheme that summarizes the social welfare pattern identified in the rural-urban gradient of Madrid Region. Curve tendencies of social welfare proxies are based on statistically significant values obtained for each socio-ecological group. Landscape pattern of each type of municipalities is indicated along the abscissa axis.



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ABSTRACT

Socio-ecological systems maintain reciprocal interactions between biophysical and socioeconomic structures. As a result of these interactions key essential services for society emerge. Urban expansion is a direct driver of land change and cause serious shifts in socio-ecological relationships and the associated lifestyles. The framework of rural-urban gradients has proved to be a powerful tool for ecological research about urban influences on ecosystems and on sociological issues related to social welfare. However, to date there has not been an attempt to achieve a classification of municipalities in rural-urban gradients based on socio-ecological interactions. In this paper, we developed a methodological approach that allows identifying and classifying a set of socio-ecological network configurations in the Region of Madrid, a highly dynamic cultural landscape considered one of the European hotspots in urban development. According to their socio-ecological links, the integrated model detects four groups of municipalities, ordered along a rural-urban gradient, characterized by their degree of biophysical and socioeconomic coupling and different indicators of landscape structure and social welfare. We propose the developed model as a useful tool to improve environmental management schemes and land planning from a socio-ecological perspective, especially in territories subject to intense urban transformations and loss of rurality.

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1. Introduction

Socio-ecological systems (SESs) are complex adaptive systems, which emerge from coupled social and ecological structures providing a powerful frame for understanding the highly dynamic interactions of ecological and societal changes (Liu et al., 2007; Ostrom, 2009; Gatzweiler, 2014). SESs are co-evolving systems maintaining a constant and reciprocal interaction and feedbacks between territorial and socio-economic structures (Norgaard, 1994; Gual and Norgaard, 2010; Lambin and Meyfroidt, 2010). As a result of these interactions key essential services for society emerge (Reyers et al., 2013).

Human transformation of land uses has led to the loss and abandonment of most intangible ecosystem services, especially those related to the regulation of not only ecological processes, but also cultural, such as local identity, traditional knowledge and spiritual enrichment (Slemp et al., 2012). Thus, current land use changes, mainly due to agricultural intensification and urbanization processes, cause serious shifts in socio-ecological interactions (Lambin et al., 2001; Plieninger et al., 2016). Urban expansion is considered worldwide as one of the primary direct drivers of land change and habitat loss and the most dramatic form of land transformation that profoundly influences biological diversity, ecosystem services and their links to human well-being and social welfare (Luck and Wu, 2002; Foley et al., 2005; Díaz et al., 2006; Fisher and Turner, 2008; Seto et al., 2012; Wu, 2013; Newbold et al., 2015). Urbanization processes not only transform rural or natural landscapes into urban systems, but also modify complex socio-ecological relationships through demographic and economic changes, as well as the associated lifestyles (Antrop, 2004; Seto et al., 2010).

In the last decades the progressive urban expansion, related to the increment in the size of cities and rural abandonment (Vos and Klijn, 2000; Antrop, 2005, 2006), has motivated the interest for understanding urban-rural gradients (McDonnell et al., 1993, 1997; Haase and Nuissl, 2010; among others). The gradient paradigm is a powerful tool for ecological research on urban influences on ecosystems (McDonnell et al., 1997; Metzger et al., 2010; Vizzari and Sigura, 2015; Salvati et al., 2017) and an appropriate framework to study sociological issues related to quality and standard of living (Savitch, 2003; Berry and Okulicz-Kozaryn, 2011; Gómez-Baggethun and Barton, 2013).

Nowadays, there are sophisticated methodological tools to quantify the interactions between nature and society (Salvati and Zitti, 2009; Salvati and Serra, 2016; Schmitz et al., 2012, 2017a). However, there is little consistency in the methods used to characterize and quantify urbanization gradients (Raciti et al., 2012; Gianotti et al., 2016) and to date, socio-ecosystem classifications in urban-rural gradients have been based on land use changes (Antrop and Van Eetvelde, 2000; Aguilera et al., 2011; Rubiera Morollón et al., 2016, among others), but not on socio-ecological interactions.

The aim of the present study is to fill this lack of knowledge by means of a conceptual and methodological approach that allows classifying SESs interactions along rural-urban gradients, based on the quantification of links between ecological and socioeconomic structures. To this end, we applied numerical procedures that enabled us i) to detect types of socio-ecological relationships along urban-rural gradients; ii) to formalize the degree of coupling between landscape and socioeconomic structures; iii) to identify the main socio-ecological indicators of this complex interaction system, and iv) to establish links between socio-ecological typology, landscape patterns and different measures of social welfare. Thus, we used different tools to achieve each of the proposed objectives. In a first step, we performed a multivariate analysis to identify groups of municipalities based on their degree of socio-ecological coupling and to know the main indicators of the interaction system. In a second step, we considered information on social welfare variables and landscape metrics for the characterization of each of the socio-ecological groups.

The outcome of this methodological approach will generate baseline information necessary for the development of socio-ecological models of land planning and management (Kasanko et al., 2006; Hara et al., 2008; Tavares et al., 2012), which can be used as a tool to maintain and restore the multifunctionality of cultural landscapes and its impact on changes in social welfare (Fisher and Turner, 2008; Fisher et al., 2009).

2. Methods

2.1. Study area

We studied the rural-urban gradient of the Madrid Region (Central Spain; Fig. 1), considered nowadays one of the European hotspots in urban development (European Commission, 2006; Kuemmerle et al., 2016). In this area, with *c.* 8000 km^2, the altitude constitutes the major ecological factor (Schmitz et al., 2007), ranging from 400 m asl in the valleys to altitudes of 2000 m on the mountain summits. One-third of the area, to the north and west, is occupied by mountainous siliceous terrain and foothills and exhibits well-differentiated altitudinal belts with oak and pine forests, upland grasslands and silvo-pastoral uses. The remainder area to the centre and east is the sedimentary basin of the Tagus River that originates an agricultural landscape. Along this environmental gradient, there is a clear variation of land cover and land uses, which gives rise to different types of landscape.

From the earliest times, this territory has been used for different human activities, such as traditional mixed rural systems based on agriculture, forestry and grazing (Schmitz et al., 2007; Schmitz et al., 2017b). Until the industrialization process in 1950′s, the boundaries between Madrid City and the countryside appeared fairly well defined. Over the last few decades, this region, as other European cultural landscapes, has changed through a bidirectional process of land use intensification and rural abandonment (Kuemmerle et al., 2016; Schmitz et al., 2017b) which has caused important modifications in the old urban-rural dichotomy (Stellmes et al., 2013). The urban growth of Madrid is a particularly paradigmatic case in Spain due to its importance, size and recent development, which mainly corresponds to the pattern of urban sprawl (Rubiera Morollón et al., 2016). Together with the loss of rurality, different socio-economic drivers have promoted an intense decentralization process, which includes the redistribution of population and employment, very high rates of housing growth and the emergence of new human settlements with important cultural and socioeconomic consequences (European Commission, 2006). A key factor in the decentralization process has been the urban mobility, based on a substantially improved transport infrastructure, with metropolitan network connections (Hewitt and Hernández-Jiménez, 2010; Díaz-Pacheco and García-Palomares, 2014).

2.2. Data collection

We focus on the characteristics of cultural landscapes and upon the socio-economy of local populations, at a municipal scale. For this reason, we considered variables that characterize both the cultural landscape and the socioeconomic structure of the area. Therefore, we collected socioeconomic and land use-land cover (LULC) data of the 179 municipalities that compose the Madrid Region (Fig. 1), using different available databases for the period 2010–2011. We considered the municipalities as analysis units because they are administrative divisions of local landscape management and governance decisions and the socioeconomic information is recorded at this scale (Schmitz et al., 2003; Salvati and Serra, 2016).

For each municipality, we collected: a) 22 landscape descriptors based on LULC (Appendix B, Table A.1; SIGA, 2010). Many of these specific land uses are considered as traditional practices. They have constituted the main traditional economic activity in this territory for centuries and have represented the most important human influence in the configuration of the current landscape (Schmitz et al., 2012); b) 29 socioeconomic descriptors of local population (Appendix B,

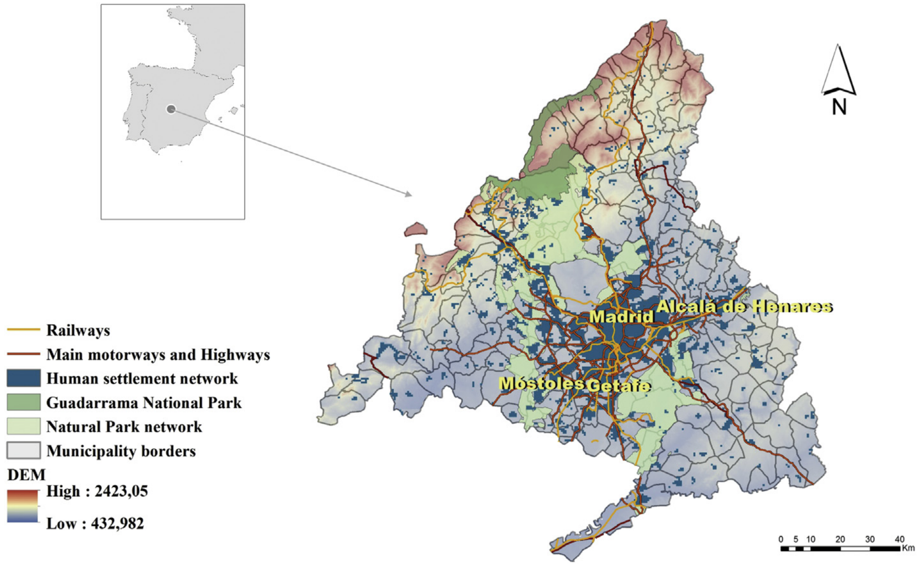

Fig. 1. Madrid Region, located in the centre of the Iberian Peninsula. The boundaries of the municipalities are shown (codes of municipalities are indicated in Supplementary material). Altitudinal gradient is mapped with a DEM. Blue shapes indicate the urban-rural network of human settlements. Municipalities may contain several settlements of different size, population density and degree of rurality. The names of main important cities, according to their size and population, are written in yellow. Green shapes show the area occupied by national and regional PAs. The main road network and railways of the region are shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table A.2; IECM, 2011). We have used these two sets of socio-ecological data to model the relationships between the landscape and the local socioeconomic structure. Subsequently, we considered another set of indicator variables of landscape patterns and social aspects. These variables were used as external descriptors characterizing the different types of socio-ecological systems previously obtained. To perform it,

Table 1
Landscape metrics used to calculate landscape patterns. A brief description of each metric and its method of calculation are indicated.

Landscape metrics	Formula	Range	Description
Shannon's evenness index	$SHEI = \frac{-\sum_{i=1}^{m}(P_i \ \ln P_i)}{\ln m}$ Pi = proportion of the landscape occupied by patch type (i). m = number of patch types (i) present in the landscape, excluding the landscape border if present.	SHEI >0, without limit	SHEI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion, divided by the logarithm of the number of patch types. In other words, the observed Shannon's diversity index divided by the maximum Shannon's diversity index for that number of patch types.
Shannon's diversity index	$SHDI = -\sum_{i=1}^{m}(P_i \ \ln P_i)$ Pi = proportion of the landscape occupied by patch type (i).	SHDI >0, without limit	SHDI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion
Patch richness	PR = m m = number of patch types present in the landscape.	PR ≥ 1, without limit	Number of different patch types present within the landscape boundary.
Splitting index	$SPLIT = \frac{A^2}{\sum_{j=1}^{n} a_{ij}^2}$ aij = area (m2) of patch ij. A = total landscape area (m2)	1 ≤ SPLIT ≤ number of cells in the landscape squared	Increases as the landscape is increasingly subdivided into smaller patches and achieves its maximum value when the landscape is maximally subdivided; that is, when every cell is a separate patch.
Edge contrast index	$ECON = \frac{\sum_{k=1}^{m}\left(p_{ijk} \times \ d_{ik}\right)}{P_{ij}} \times (100)$ P_{ijk} = length (m) of edge of patch ij adjacent to patch type (k) d_{ik} = dissimilarity (edge contrast weight) between patch types i and k. P_{ij} = length (m) of perimeter of patch ij.	0 ≤ ECON ≤100	This index is a relative measure of the amount of contrast along the patch perimeter.
Euclidean nearest neighbor distance	ENN = h_{ij} h_{ij} = distance (m) from patch ij to nearest neighboring patch of the same type (class), based on patch edge-to-edge distance, computed from cell center to cell center.		Distance (m) to the nearest neighboring patch of the same type, based on shortest edge-to-edge distance. Has been used extensively to quantify patch isolation
Largest patch index	$LPI = \frac{\text{Max (a)}}{A} \times (100)$ a_{ij} = area (m2) of patch ij. A = total landscape area (m2)	0 < LPI < 100	Percentage of the total landscape comprising the largest patch

c) we calculated municipal spatial patterns expressed by landscape metrics (Table 1, see below the calculation procedure) and d) we collected indicators of social welfare, understood from two dimensions. The first dimension, named “spatial welfare” according to the perspective of Grazi et al. (2007), is based on estimation models of land occupation (area occupied per inhabitant or percentage of occupied area) and represents social benefits of land use in terms of quantity and space (Zhang et al., 2016): rates of land occupation by urban areas, rates of land occupation by infrastructure and industrial facilities and percentage of land occupied by protected areas, recognized both by the Spanish and the international legislative framework (Naredo and García-Zaldívar, 2008; Europarc, 2017; Appendix C). The second welfare dimension assumes indicators of standard of living, so called “objective indicators of quality of life” or “social indicators” (Cummins et al., 2003; Marans, 2003), related to health and education accessibility, available incomes and income inequality (Appendix C; IECM, 2011).

2.3. Calculating landscape patterns

We used a rasterized CORINE Land Cover Map for the year 2012, considering seven land use aggregated classes, namely: coniferous forests, broad-leaved forests, shrublands, grasslands, arable lands, urban and water bodies. We obtained these classes from the reclassification of the CORINE land cover classes into more meaningful and representative categories according to the land use and dynamic of the region studied (i.e: wineyards and olive groves were reclassified into arable lands). Then, using a round moving window with a radius of 100 m, we generated raster maps of a set of landscape metrics at landscape scale.

For the selection of these landscape metrics, we followed criteria based on their descriptive ability of the landscape patterns of the study area, ease of interpretation, non-redundancy and comparability (Su et al., 2012; Zhang and Gao, 2016). The seven selected land metrics are the following (see a brief description of each metric in Table 1): Shannon's diversity index (SHDI, quantifies landscape diversity and it is a good indicator of landscape heterogeneity), Shannon's evenness index (SHEI, measures the distribution of area among patch types; it is contrary to dominance), Patch richness index (PR, measures the number of patch types present), Splitting index (SPLI T, measures the degree of the landscape fragmentation), Edge contrast index (ECON, a contrast metric that measures the magnitude of difference between adjacent patches), Euclidean nearest neighbor distance (ENN, describes the degree of spatial isolation of patches and, therefore, the degree of landscape connectivity) and Largest patch index (LPI, measures the size of patches and the amount of edge created by these patches and represents an indirect measure of landscape homogeneity). Data were treated with ArcGis software V.10.1 (ESRI, 2012) and Fragstats V.4.2 (McGarigal et al., 2012).

2.4. Quantifying socio-ecological relationships

2.4.1. First step: spatial assignment of socio-ecological descriptors

We assigned the two sets of 22 landscape and 29 socioeconomic descriptors to the municipalities studied using two matrices of georeferenced quantitative data. The first described the municipalities by means of land use variables, quantified as a percentage of the occupied area in each municipality. The second matrix contained the socioeconomic characteristics assigned to the municipalities (the measurement unit of each socioeconomic variable is indicated in Appendix B, Table A.2).

2.4.2. Second step: calculating socio-ecological coupling

We quantified the relationship between socio-economy and landscape through a canonical correlation analysis (CCA), which is used to determine the links between two or more sets of variables (Sherry and Henson, 2015). CCA is a constrained ordination technique, which means that the ordination of the objects represents only the data structure that maximizes the relationship with a second matrix of predictor variables. The relationship between both matrices is made by means of weighted multiple regression techniques. In study cases with multiple dependent and independent variables, canonical correlation is the most appropriate and powerful multivariate technique (Hair et al., 2014). Previously, we had checked data to account for analytical requirements. We projected the coordinates of municipalities on the ordination plane and identified and classified socio-ecological types by segmenting the first two axes into four equal intervals significantly different (Ruiz-Labourdette et al., 2013). We assigned municipalities to the socio-ecological groups identified on the plane according to their proximity to the centroid of each group by means of Mahalanobis distances, MDij,

$$\mathrm{MD}_{i,j}^2 = (x_i - x_j)' V_w^{-1} (x_i - x_j) \qquad (1)$$

where vectors xi and xj represent two points in the p-dimensional space and Vw the matrix of covariance among groups (De Aranzabal et al., 2008).

2.5. Characterizing socio-ecological types by landscape indices and human-welfare proxies

We characterized the four socio-ecological types of municipalities by means of landscape metric indices and standard of living and spatial welfare variables (Tables 1 and 2). The characterization was carried out using a mean comparison test that allowed us to characterize a qualitative variable by quantitative variables. Thus, a Fisher F-test ($k > 2$) was performed to determine the statistical significance of the variables (landscape indices and social welfare proxies) in the municipality types (socio-ecological groups). The more the mean of a variable in a group is significantly different from the mean of that variable in the whole group, the stronger the link between the characterizing quantitative variable and the qualitative category (Levart et al., 2000). Groups characterized by a high range of statistically significant variables have greater possibilities to enjoy of certain land uses and services associated with social welfare proxies and landscape metric indices. We used Xlstat (vs. 2016.02.23567) to perform these analyses.

3. Results

The ordination plane shows the distribution of the municipalities of the Madrid Region along a rural-urban gradient according to their socio-ecological characteristics (Fig. 2). The two first axes of CCA are generated to yield the largest possible correlation between variables, and together explain 43.79% of the data variance. The CCA plane allows us to interpret the territory in terms of socio-ecological links.

The first axis (22.94% of variance explained) is the product of the maximum possible correlation between LULC and socioeconomic variable scores (Appendix C). This axis explains the landscape variation along an urban-rural gradient, from urban systems at the negative end of the axis (mainly characterized by public transport services, urban infrastructures and associated green areas, number of inhabitants and non-native population), to rural areas at the positive end of the axis (characterized by the distance from the capital, agricultural lands, grasslands, rural and industrial facilities and an unstable agricultural labor market).

The second CCA axis (20.85% of variance explained) has maximal site-variables correlation, subject to the constraint that axes are orthogonal. It represents a gradient from residential areas, with a high population density and transport infrastructures (negative end of the CCA axis), to agricultural systems, linked to a productive primary sector (positive end of the CCA axis; Fig. 2).

The segmentation of the CCA plane and the application of Mahalanobis' distance analysis (1) (≥98% of correct classifications in all cases) point out that there are currently four municipality types in

Table 2
Characterization of the socio-ecological groups of Madrid Region according to (a) social welfare proxies and (b) landscape metric indices. Data are expressed as mean values per municipality types. Statistically significant values (Fisher F-test; *p*-value ≤0.05) are indicated in bold and standard deviations in parentheses.

a) Social welfare

Indicators	Variables	Urban system	Peri-urban system	Rural system in urban transition	Rural system
a_1) Spatial welfare	Urban land-uses	**1.78**(0.98)	**1.29**(0.51)	1.02(0.07)	0.63(0.12)
	Residential land-uses	1.65(0.46)	2.48(0.05)	**2.90**(0.04)	**3.28**(0.10)
	Industrial/infrastructure land-uses	0.92(0.90)	**1.63**(0.09)	1.32(0.07)	0.37(0.19)
	Green and sport zones	1.13(0.73)	**0.81**(0.07)	0.44(0.05)	0.00(0.15)
	Urban sprawl	1.11(0.99)	**1.55**(0.10)	1.13(0.07)	0.67(0.21)
	Water-bodies and reservoirs	0.38(0.95)	0.40(0.15)	0.50(0.08)	**1.38**(0.24)
	Forest land-uses	1.60(0.55)	1.03(0.05)	1.14(0.04)	**1.59**(0.11)
	Agricultural land-uses	0.00(0.83)	0.05(0.02)	**0.18**(0.01)	0.03(0.01)
	Guadarrama National Park	0.00(0.34)	**0.09**(0.04)	0.06(0.02)	0.20(0.14)
	Regional Park of Upper Manzanares River Basin	0.96(0.49)	**0.26**(0.05)	0.11(0.04)	0.00(0.10)
	Regional Park of Guadarrama River´s Middle Course	0.00(0.46)	**0.25**(0.04)	0.11(0.03)	0.00(0.09)
	Regional Park of Madrid Southeast	0.39(0.79)	**0.22**(0.07)	0.06(0.05)	0.00(0.14)
	Sites of Community Importance (Natura 2000)	1.56(0.75)	**1.34**(0.07)	0.98(0.05)	1.34(0.15)
	Special Protection Area for Birds (Natura 2000)	1.56(0.75)	**1.34**(0.07)	0.98(0.05)	1.34(0.15)
	Natural Habitat of European Interest (Natura 2000)	1.51(0.56)	1.15(0.06)	1.32(0.04)	**1.51**(0.14)
	Biosphere Reserves (MaB programme)	0.98(0.55)	0.24(0.05)	0.12(0.04)	**0.38**(0.11)
a_2) Standard of living	School enrollment	0.18(0.14)	**0.22**(0.01)	0.16(0.01)	0.02(0.03)
	Equity (GINI coefficient)	0.53(0.27)	0.50(0.03)	**0.52**(0.02)	0.14(0.05)
	Health centers	0.40(0.14)	0.62(0.03)	**0.23**(0.02)	0.00(0.04)
	Available per capita income	19.4(0.82)	**16.0**(0.08)	14.7(0.06)	12.0(0.17)

b) Landscape metrics

	Variables	Urban system	Peri-urban system	Rural system in urban transition	Rural system
	Shannon's Evenness (SHEI)	0.16(0.08)	0.17(0.12)	0.21(0.05)	**0.26**(0.00)
	Shannon's Diversity (SHDI)	1.98(0.05)	1.21(0.00)	1.76(0.08)	**1.95**(0.04)
	Patch richness (PR)	4.00(0.56)	**4.15**(0.06)	3.86(0.04)	3.51(0.11)
	Splitting (SPLIT)	3.73(0.09)	**3.96**(0.04)	3.89(0.04)	3.92(0.47)
	Edge Contrast (ECON)	35.16(0.32)	**41.60**(0.02)	26.91(0.12)	21.14(0.04)
	Euclidean nearest neighbor distance (ENN)	101.39(8.02)	**91.84**(0.80)	89.10(0.60)	86.14(1.64)
	Largest Patch (LPI)	68.96(0.12)	68.32(0.15)	**69.65**(0.02)	67.16(0.05)

the study area. This analysis highlights the transition from coupled rural SESs to another type of coupled system, which emerges from the interaction between the development of urban areas and services sector (decoupled rural SESs). Between these two coupled systems we can detect two types of municipalities in rural-urban transition, which are characterized by diverse degrees of coupling between biophysical and socioeconomic structures (Fig. 2). The detected set of municipality types has different socio-ecological characteristics and is associated to dissimilar landscape patterns, spatial welfare and standard of living indices (Table 2; Fig. 3). Madrid City shapes the group named "Urban system", characterized by a heterogeneous mixture of different, contrasted and poorly connected land use types (see the values of SHDI, PR, ECON, ENN; Table 2b), with a high occupation area of urban land uses per inhabitant (Table 2a_1). The values of several spatial welfare and standard of living indicators are moderately high, as well as the income inequity (GINI index; Table 2a_2). On the opposite end of the CCA plane, the "Rural System" comprises municipalities whose inhabitants enjoy a large quantity of residential land uses and forest and agricultural lands (Table 2. a_1). The landscape pattern is heterogeneous, maintaining high and significant values of land use diversity, evenness

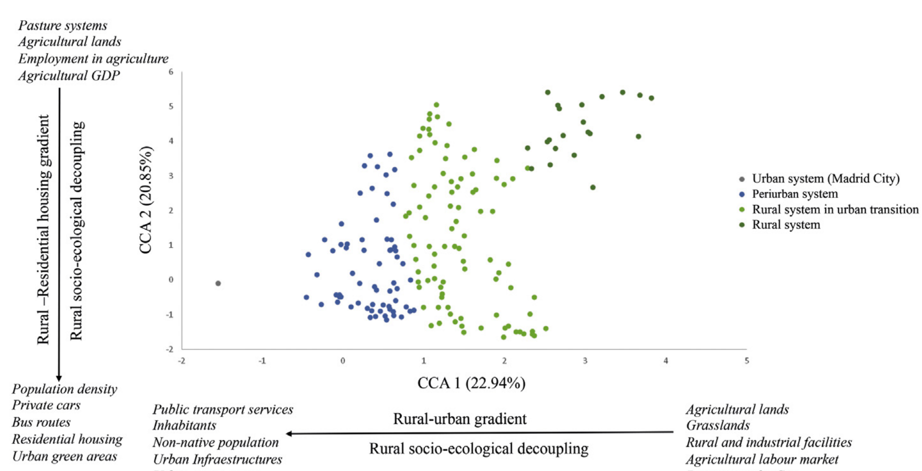

Fig. 2. CCA plane showing the distribution of municipalities of Madrid Region according to their socio-ecological characteristics. Biophysical and socioeconomic variables with the highest loadings are indicated at the end of the two main axes. Appendix Aa,b shows the biophysical and socioeconomic variables used in the analysis. Appendix B indicates the CCA factors loading of the socio-ecological variables.

and connectivity (SHDI, SHEI, ENN; Table 2b). The cultural and natural importance of this landscape type has been recognized by means of protection figures (Table 2a_2). Although the rural lifestyle indicates a relatively high spatial welfare, the values of the standard of living indicators are low. However, the GINI index is lower than the rest of groups, indicating the best income distribution (Table 2a_2). The "Periurban system", surrounding urban system, has a population with a high standard of living and spatial welfare as indicated by the available incomes per capita and the accessibility to educational, health and land use services (Table 2a_1,a_2). Even though much of the area of this system has several nature conservation statuses, land uses are contrasted, highly fragmented and unconnected (ECON, SPLIT, ENN; Table 2b) and the land planning is mainly addressed to the promotion of urban sprawl (Table 2a_1). Between periurban and rural systems, there are some municipalities that define a system in socio-ecological transition from rural to urban landscapes ("Rural system in urban transition"). Landscape metric indices reveal large homogeneous patches (LPI), which maintain contrasting borders (ECON) between agricultural lands and urban residential development (Table 2a_1). From a societal perspective, the accessibility to health services and a high and significant degree of income inequality stands out (Table 2a_1,a_2).

We used the results of CCA to spatially identify and map the current socio-ecological configuration of the Madrid Region. The overlap of the socio-ecological pattern with the main road network and railways of the region shows a close interrelation between them (Fig. 3). The main socio-ecological processes detected along the rural-urban gradient of the Madrid Region implies changes of landscape structure and social welfare not conditioned by the altitudinal and geomorphological gradient of the study area.

4. Discussion

In this paper we applied a methodological approach that allows identifying groups of municipalities according to their socio-ecological links. The four types of municipalities detected in the Madrid Region are distributed along an urban-rural gradient characterized by indicators of landscape structure, spatial welfare and standard of living. Although the delimitation of landscape types is complicated and unstable because of the dynamism of the nature-society interactions (Antrop, 2004), the defined groups, based on socio-ecological interactions, are similar to those found by other authors using different methodologies (Serra et al., 2014a; Vizzari and Sigura, 2015; Gianotti et al., 2016).

The opposite rural and urban systems identified on the CCA plane (Fig. 2) are coupled socio-ecosystems that establish a strong link between landscape and either primary or tertiary socio-economy sectors, respectively. The changing socio-ecological relationships from rural to urban systems cause a rural decoupling and its corresponding environmental consequences (Ribeiro Palacios et al., 2013), because a strong human-environment interaction in a given system can mean an intense decoupling for another (Schmitz et al., 2017a). These two systems share the non-significance of the indicators of spatial welfare and the standard of living of their inhabitants, the landscape heterogeneity and the scarce weight of land protection efforts (Table 2), as other authors have also described (Antrop, 2000a, 2000b, 2004; Wittemyer et al., 2008).

The gradual transformation of the countryside generates systems in rural-urban transition processes (Webster and Muller, 2009). In this case, the gradient analyzed underlines the transition from traditional rural systems to urban consolidation through a complex and unclear peri-urbanization process that makes the urban-rural limits within the gradient difficult to identify (Fig. 2). The progressive expansion of urban areas and the increment of human settlements in the surroundings of rural and natural lands result in the acceleration of soil sealing and degradation, which softens the demarcation line between urban and rural areas (Amato et al., 2016). Thus, in most cases, the boundaries between urban and rural systems are unclear and their identification has a high degree of uncertainty. This process gradually changes the rural landscape and associated style of life (Table 2), turning it into an urban one and generating a changing mix of urban and rural activities and functions spatially expressed as land use mosaics, with a high variety of LULC and a complex and fragmented morphology (Antrop, 2000a, 2004; Tavares et al., 2012). In this way, several authors affirm that the urbanization of rural landscapes is a key factor in the process of landscape fragmentation and creates new and heterogeneous landscapes in the vicinity of towns and cities (Antrop and Van Eetvelde, 2000; Yang and Liu, 2005; Tang et al., 2006). Peri-urban areas, created by the transformation of the countryside around urban settlements, are characterized by multifunctional ecological processes and complex spatial planning and they may become the dominant urban form of the twenty-first century (Antrop and Van Eetvelde, 2000; Antrop, 2004; Ravetz et al., 2013; Vizzari and Sigura, 2015). In this type of highly dynamic areas land use changes can occur in a systematic or random manner or even both ways (Tavares et al., 2012). The values of the standard

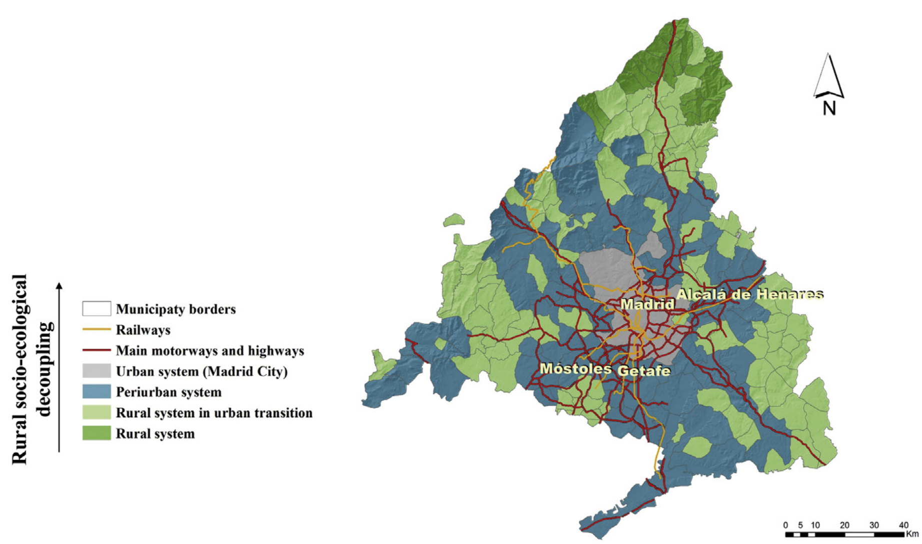

Fig. 3. Mapping the socio-ecological groups identified in Madrid Region according CCA analysis: coupled urban system (light grey); peri-urban system (blue); rural system in urban transition (light green); coupled rural system (dark green). The main road network and railways of the region are mapped. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of living and spatial welfare reach the highest levels in these peri-urban systems and in the rural in urban transition systems.

The regional socio-ecological pattern define is closely related to the development of transport infrastructures (Fig. 3), which act as mobility corridors connecting the urban area with small towns and other dispersed settlements (Forman, 2014). These transport networks involve an increase in the mobility of people, favouring the interconnection between places of residence and work, the exchange of goods and information (Rosell et al., 2003; Serra et al., 2014b) and, therefore, the urban sprawl, expressed as a dispersed pattern along the main motorways and highways. The interaction between urban sprawl and new communication networks, conditions the spatial organization of the landscape (Antrop, 2004). When the intensity of land use and management increases, the spatial configuration and heterogeneity of different types of mosaics in the landscape grows. As a result of this process, loss and fragmentation of habitats can appear. Moreover, transformation and degradation of the landscape threaten the sustainability of ecosystem services (Lindenmayer and Fischer, 2013), generating alterations in ecological functions and processes that depend on the flow of energy and material through the landscape.

Peri-urban and rural in urban transition systems are associated with the establishment of protected natural areas (PAs) (Table 2a), especially designed to preserve cultural landscapes and their diversity of land uses, habitats and species and other benefits and ecosystem services that biodiversity provides to social welfare (Naughton-Treves et al., 2005; Kareiva et al., 2007; Martín-López and Montes, 2015). Nevertheless, several studies confirm that these PAs do not mitigate the accelerated dynamics of landscape homogenization and the loss of landscape multifunctionality observed in the urban-rural transitions (Schmitz et al., 2012; Amici et al., 2015; Schmitz et al., 2017b; van der Plas et al., 2016). Often within regulations schemes of PAs some human activities are inhibited, which promotes land abandonment and loss of rurality, with a negative impact on welfare (Glowka et al., 1994; Wilkie et al., 2006; Schmitz et al., 2012; Pullin et al., 2013).

In addition, our results indicate that the increase in urban and industrial land uses is related to the establishment of protected natural areas (Table 2a). Although the usually proposed strategies to regulate and control urban development in natural and rural areas include the establishment of PAs for nature conservation among the land use planning schemes (Lambin and Meyfroidt, 2011; Palomo et al., 2014), the link between urban sprawl and land designated as PAs has been proved worldwide (Trzyna, 2007; Tavares et al., 2012). These results suggest that PAs favor, rather than avoid, the development of human settlements in their surrounding lands, which would imply an undesirable shortening of the distance between PAs and cities and highlight the potential threat to biodiversity conservation and PAs effectiveness (McDonald et al., 2008, 2009; Wittemyer et al., 2008; Martín-López et al., 2011).

In the study area the use of selected land metrics has proved useful and allowed us to know clearly the main changes of the landscape patterns associated to the changing socio-ecological coupling through rural-urban gradients. Several authors emphasize the need to incorporate landscape patterns in the socio-ecological context being examined (Herold et al., 2005; Ramalho and Hobbs, 2012; Tavernia and Reed, 2009, among others). Specific land metrics derived from ecological and social processes reflect the unique context and the spatial heterogeneity of a territory (Gianotti et al., 2016).

Our results can be useful to get an approximation of the level of social welfare that exists in each socio-ecological group. As we understand social welfare as the ability of individuals to satisfy their basic and multiple needs in the context of economic equity (Summers and Smith, 2014), we observe that the peri-urban system of the Madrid Region is most likely to maximize the welfare of its inhabitants. These transition areas provide a wide variety of services to society that benefits all social strata (Douglas, 2006), since they gather lifestyles and economic activities both rural and urban and are occupied by people of different social classes. According to different studies in Europe and USA (Berry and Okulicz-Kozaryn, 2011; Easterlin et al., 2011), rural systems in the study area have a better distribution of available income (low level of GINI index), although it is also characterized by low values of the standard of living proxies, indicated by the income levels and difficulties in accessing social services such as education or health care (Table 2b). The Wirthian theory suggests that happiness is low in large cities and achieve high levels in small towns and rural areas (Berry and Okulicz-Kozaryn, 2011; Okulicz-Kozaryn, 2015). However, available income and health and education accessibility are some of the objective components of standard of living (Blanchflower and Oswald, 2011) and both are limited in the studied rural areas. There are different approaches to estimate the ecological consequences of urbanization processes at landscape level. However, rural-urban gradients have become a useful tool to study the different characteristics of socio-ecosystems in urban-rural contexts (McDonnell and Pickett, 1990, McDonnell et al., 1997, Kroll and Müller, 2011, Hewitt and Escobar, 2011, among others). Our model goes one-step further in the socio-ecological characterization as it allows the determination of the degree of coupling between the biophysical and socioeconomic structures. The application of this tool in rural-urban gradients can generate conclusive results that are necessary and applicable in the management of landscape (Kasanko et al., 2006; Hara et al., 2008; Tavares et al., 2012).

5. Conclusions

The application of an integrated quantitative model has allowed us to describe the Madrid Region in terms of socio-ecological networks, differentiating types of municipalities and characterizing them according to landscape metrics and proxies of social welfare. The analysis performed indicates that socio-ecological coupling is high in both urban and rural areas albeit in different ways. Highly heterogeneous rural countryside gradually changes toward an urban system which presents new and also highly heterogeneous landscapes. Urban areas are linked to economic activities of the tertiary sector, while in rural areas activities related to the primary sector are still maintained. Neither of both systems achieves high levels of welfare. Peri-urban and rural areas in transition from rural to urban systems show uncoupling structures between socio-economy and nature and a highly fragmented and unconnected landscape, but the population of these dynamic transition areas enjoys the highest levels of spatial welfare and standard of living in the region. This set of socio-ecological network configurations of the Madrid Region is closely linked to the improvement and development of transport infrastructures, along which there have been intense processes of sprawl and urban growth.

Although the results obtained should be contextualized in accordance with the economic development of the region or country under study, the applied model proves to be useful to provide insight of the socio-ecological settings of a region. The classification and spatial identification of the socio-ecological types of a territory, as well as the quantification of their degree of biophysical and socioeconomic coupling should be considered to improve environmental management schemes and socio-ecological land planning beyond municipalities' boundaries, especially in territories subjected to intense tendencies of urban expansion and loss of rurality.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2017.08.215.

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Appendix A

Table A.1
Land use and land cover (LULC) descriptors recorded in each municipality of Madrid Region (SIGA, 2010; 1:50,000; 500 m pixel resolution). The unit of measure was percentage area respect to municipal area.

Landscape descriptors (%)
Commercial areas
Dry land farming
Extensive agricultural lands
Grasslands
Infrastructures
Irrigated herbaceous crops
Mediterranean forests
Mediterranean shrubland
Middle and high mountain shrubland
Olive plantations
Orchards
Pasture systems
Pastures with trees ("dehesas")
Residential housing
Riparian forests
Rural and Industrial facilities
Scots pine forests
Urban areas
Urban equipment
Urban green areas
Vineyards
Water bodies

Table A.2
Socioeconomic variables recorded in each municipality of the study area (IECM, 2011). Units of measurement are indicated.

Variables	Unit
Agricultural sector GDP	Percentage
Bed in hotels	Rate
Bus routes linking to Madrid city (per inhabitant)	Rate
Bus routes linking to other small towns(per inhabitant)	Rate
Bus shelters (per inhabitant)	Rate
Cattle farms (per inhabitant)	Rate
Distance to Madrid city	Kilometer
Employment in agricultural holdings	AWU
Goat farms (per inhabitant)	Rate
Horse farms (per inhabitant)	Rate
Industrial sector GDP	Percentage
Inhabitants	Number
Intra-urban bus routes (per inhabitant)	Rate
Large holdings (50 ha and more)	Number
Medium holdings (from 20 to 50 ha)	Number
Native population	Rate
Non-native population	Rate
Pig farms (per inhabitant)	Rate
Population density	Inhabitats/km^2
Public transport services	Rate
Rural cadastre value (per rural area)	Thousand €
Services sector GDP	Percentage
Small holdings (<20 ha)	Number
Total private cars (per inhabitant)	Rate
Unemployment in agriculture (per inhabitant)	Rate
Unemployment in Industry (per inhabitant)	Rate
Unemployment in services (per inhabitant)	Rate
Urban cadastre value (per urban unit)	Thousand €
Water consumption (per capita)	Rate

Appendix B. Set of variables used to identify social-welfare proxies and landscape patterns. For each variable the unit of measurement is indicated (IECM, 2011; Europarc, 2017; Naredo and García-Zaldívar, 2008)

a) Social welfare

	Variables	Units
a_1) Spatial welfare	Urban land-uses	m^2 per inhabitant
	Residential land-uses	m^2 per inhabitant
	Industrial/infrastructure land-uses	m^2 per inhabitant
	Green and sport zones	m^2 per inhabitant
	Urban sprawl	m^2 per inhabitant
	Water-bodies and reservoirs	m^2 per inhabitant
	Forest land-uses	m^2 per inhabitant
	Agricultural land-uses	m^2 per inhabitant
	Guadarrama National Park	Percentage
	Regional Park of Upper Manzanares River Basin	Percentage
	Regional Park of Guadarrama River's Middle Course	Percentage
	Regional Park of Madrid Southeast	Percentage
	Sites of Community Importance (Natura 2000)	Percentage
	Special Protection Area for Birds (Nature 2000)	Percentage
	Natural Habitat of European Interest (Nature 2000)	Percentage
	Biosphere Reserves (MaB programme)	Percentage
a_2) Standard of living	School enrollment	Students per inhabitant
	Equity (GINI coefficient)	Index
	Health centers	Number per 10.000 inhabitant
	Available per capita income	Thousand € per year

b) Landscape metrics

Variables	Units
Shannon's evenness (SHEI)	Index
Shannon's diversity (SHDI)	Index
Patch richness (PR)	Index
Splitting (SPLIT)	Index
Edge contrast (ECON)	Index
Euclidean nearest neighbor distance (ENN)	Meters
Largest patch (LPI)	Index

Appendix C. Scores of LULC and socioeconomic variables used in the CCA. Variables with greater weights are indicated in bold

a)

Landscape descriptors	CCA1	CCA2
Commercial areas	0.13	−0.32
Dry land farming	0.06	**0.52**
Extensive agricultural lands	**0.35**	−0.02
Grasslands	**0.21**	−0.11
Infrastructures	**−0.62**	−0.12
Irrigated herbaceous crops	0.13	0.45
Mediterranean forests	**−0.53**	0.18
Mediterranean shrubland	0.19	0.03
Middle and high mountain shrubland	0.15	0.07
Olive plantations	0.15	0.32
Orchards	0.05	0.11
Pasture systems	0.14	0.22
Pastures with trees ("dehesas")	−0.25	**0.46**
Residential housing	−0.19	**−0.60**
Riparian forests	0.15	0.38
Rural and industrial facilities	0.20	−0.38
Scots pine forests	0.09	0.16

(*continued*)

a)

Landscape descriptors	CCA1	CCA2
Urban areas	0.00	−0.39
Urban equipment	−0.14	−0.36
Urban green areas	−0.41	**−0.47**
Vineyards	0.07	0.33
Water bodies	−0.27	0.36

b)

Socioeconomic variables	CCA1	CCA2
Agricultural sector GDP	1.01	**1.57**
Bed in Hotels	0.29	−0.19
Bus routes linking to Madrid city	0.69	0.27
Bus routes linking to other small towns	0.82	0.72
Bus shelters	0.65	−0.11
Cattle farms	0.97	1.05
Distance to Madrid city	1.10	1.25
Employment in agricultural holdings	**1.32**	**1.73**
Goat farms	0.88	0.84
Horse farms	0.91	0.68
Industrial sector GDP*	0.81	0.90
Inhabitants	−0.41	−0.04
Intra-urban bus routes	0.33	−0.24
Large holdings	0.97	1.03
Medium holdings	1.04	1.01
Native population	0.97	1.30
Non native population	**−0.49**	−0.08
Pig farms	0.94	1.36
Population density	0.44	**−0.32**
Public transport services	**−0.66**	−0.02
Rural cadastre value	0.29	0.99
Services sector GDP	0.87	0.85
Small holdings	0.89	1.23
Total private cars	0.55	**−0.30**
Unemployment in agriculture	**1.20**	1.49
Unemployment in Industry	0.80	1.03
Unemployment in services	0.80	0.96
Urban cadastre value	0.78	0.66
Water consumption	0.90	0.95

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ARTÍCULO 04

Título: People and nature in the Fuerteventura Biosphere Reserve (Canary Islands): socio-ecological relationships under climate change

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Resumen:

Este trabajo analiza la interdependencia entre la naturaleza y la sociedad en términos de redes socio-ecológicas, en las que los sistemas humanos y biofísicos están interrelacionados. La aplicación de un modelo cuantitativo, basado en un análisis de correlación canónica, en la isla de Fuerteventura (Archipiélago Canario), permitió detectar los principales indicadores de las relaciones entre el hombre y el paisaje y predecir cambios potenciales basados en la simulación de cambios ambientales. En las últimas décadas, el paisaje de la isla de Fuerteventura se ha modificado: los componentes naturales y los usos agrarios culturales han disminuido, mientras que la población ha aumentado debido a la inmigración, principalmente desde la España peninsular y otros países europeos. La isla muestra una transición desde un sistema socio-ecológico local acoplado a uno basado en la interacción del medio con el turismo costero que desvincula a los habitantes nativos de su paisaje y de las prácticas tradicionales agrarias. Considerando que la vulnerabilidad y la adaptación al cambio climático representan conjuntos críticos de interacciones potenciales en las Islas Canarias, en este artículo se presenta un modelo y un mapa del sistema socio-ecológico de la isla bajo cuatro escenarios del Panel Intergubernamental sobre Cambio Climático. Los resultados muestran el desacoplamiento rural a través de la "desgrarización" y la "deruralización", así como también enlaces al sistema de turismo.

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People and nature in the Fuerteventura Biosphere Reserve (Canary Islands): socio-ecological relationships under climate change

THEMATIC SECTION
Humans and Island Environments

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SUMMARY

This paper analyses the interdependence between environment and society in terms of socio-ecological webs, in which human and biophysical systems are linked. A quantitative model, based on canonical correlation analysis applied in Fuerteventura Island (Canary Archipelago), detected indicators of human–landscape relationships and predicted potential shifts based on simulated environmental changes. In the last few decades, the landscape of Fuerteventura Island has changed: natural components and cultural agrarian uses have decreased, while the population has increased due to immigration, mainly from mainland Spain and other European countries. The island shows a transition from a coupled local socio-ecosystem to one based on the interaction between environment and coastal tourism that decouples native inhabitants from the landscape and traditional land-use practices. As vulnerability and adaptation to climate change represent critical sets of potential interactions in Canary Islands, a model and a map of the socio-ecological system under four Intergovernmental Panel on Climate Change scenarios show rural decoupling through 'deagrarianization' and 'deruralization', as well as stronger links to the tourism system.

Keywords: coupled socio-ecological systems, deagrarianization, deruralization, humans in nature, IPCC scenarios, local populations, socio-ecological webs, tourism system

INTRODUCTION

Socio-ecological systems (SESs) theory links the influence of economy with the functioning of ecosystems (Ostrom 2009). SESs, emerging from complex and coupled social and ecological structures (Gatzweiler 2014), comprise natural–sociological interactions, depend on the environmental conditions of each region and provide a wide range of essential services to society (Haines *et al.* 2006; Gual & Norgaard 2010). There are neither social systems without nature nor ecosystems without people (Petrosillo *et al.* 2015).

Socio-ecological interdependencies may have applications in landscape assessment, planning, conservation and management. Protected area conservation planning has frequently focused on the biophysical components; nevertheless, these areas are also SESs that include stakeholders interacting in a shared environment (Schmitz *et al.* 2012; Cumming *et al.* 2015). In particular, biosphere reserves point to the interconnection of human and natural landscapes. Hence, these reserves offer scope for understanding the interplay between complex mixtures of driving forces and anthropogenic stress factors on SESs (UNESCO 2005).

Different analytical tools are necessary to formalize the relationship between environment and society. The most productive have been those arising from systemic approaches (Norberg & Cumming 2008; Ostrom 2009), where the formalization allows the identification and quantification of the degree of interdependency and coupling between the two systems (Parcerisas *et al.* 2012; Gatzweiler 2014). Furthermore, the correspondence between different ways of inhabiting the territory and landscape structures allows the generation of future scenarios, thus facilitating the work of environmental managers and decision makers (Holling 2001; Folke *et al.* 2002; Gunderson & Holling 2002). The Millennium Ecosystem Assessment (MEA 2005) highlighted the development of scenarios and models to support key socio-ecological issues and decision making. This could reduce the uncertainties of environmental strategies such as those under the influence of climate change (CC).

The goal of this paper is to understand the interactions between social, economic and ecological systems in the island of Fuerteventura, emphasizing the concept of humans in nature and modelling socio-ecological changes over three decades (1980–2010). Fuerteventura is a desert territory and its whole area was designated by UNESCO as a biosphere reserve in 2009. The SES of Fuerteventura is rapidly changing due to socio-economic changes that made traditional

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agriculture unprofitable. As a result, there has been land abandonment and losses of natural–cultural values, as well as local people's identity, including losses of linkages between island inhabitants and their rural cultural landscape. Rural people in arid zones ultimately depend on the effective use of natural resources, and it is recognized that these environments are expected to undergo significant changes resulting mainly from CC (Verón *et al.* 2006; Reynolds *et al.* 2011).

We formalize a quantitative model of relationships between the structure of the society and the biophysical characteristics of this island, assuming that the natural capital establishes the ecological limits of the SES (WFNC 2015). Considering that the vulnerability and adaptation to CC constitute a critical set of society–environment interactions (Lorenzoni *et al.* 2000; IPCC 2007), we have modelled changes in the SES under CC scenarios of the Intergovernmental Panel on Climate Change (IPCC). The model allows both detecting of the degree of coupling between human and natural systems and predicting potential changes in the socio-economic structure based on simulated environmental conditions.

METHOD

Study area

Fuerteventura is one of the seven islands of the Canary Archipelago, with an area of 1657 km^2. The volcanic structure is 20 million years old, and this age determines its eroded topography and limited altitudinal variation. The island, which is considered to be the most arid region of Europe, is a desert with a relatively homogeneous landscape. Monthly average temperatures are 17–20°C throughout the year, although it can suddenly rise due to sub-Saharan influences. Precipitation is less than 200 mm/year and irregular. Insolation is *c.* 2800 hours of sunshine/year and winds are intense and constant, which favours evapotranspiration.

Limited water availability and centuries of agriculture have contributed to the current landscape of scarce vegetation and a lack of forests. Most of the island territory is colonized by scrub with scarce coverage because of the exploitation of vegetation for fuel and intense and extensive long-standing goat grazing. Traditional goat farming is still an economically important activity on the island. It is considered by some conservationists as a threat to plant species richness, while others see it as an activity in a historical equilibrium with nature that has been modified by the arrival of tourism and other new activities (Gangoso *et al.* 2006). Today, residual agrarian and fishing activities coexist with the conservation of the natural and cultural landscape, which is very attractive for visitors and the development of tourism (Díaz *et al.* 2010).

Shrubland and coastal vegetation are the most abundant plant formations of the island (Fig. 1). The former has increased since 1980, while the characteristic vegetation of sandbanks and salt marshes has declined. Deciduous native groves, mainly willows, tamarisks and palm, are almost the only arboreal representatives of native vegetation, barely surviving in ravines and valley bottoms. Cultural land uses constitute a negligible proportion of the area of the island, and they have an important tendency for shrub encroachment as a consequence of the abandonment of traditional agricultural activities. Human population growth has nevertheless occurred due to the recent increase in non-native people (Fig. 1).

Data collection

We focus on the biophysical characteristics of the study area and the socio-economy of the local population. Thus, we consider variables characterizing natural capital, land uses and the socio-economic structure of the island.

Large scale

We collected available data from the temporal variation of the natural vegetation and land uses over a period of 30 years (SIGA 1980–2010) and from the native and non-native human population (number of inhabitants) during 2000–2015 (ISTAC 2016).

Human settlement scale

Fuerteventura has six municipalities composed of 51 rural human settlements (HSs; small towns, villages and hamlets) sparsely distributed within their territorial limits. We selected the areas of influence of the HSs as spatial reference units (Appendix S1) (available online). These spatial sectors were used as units of analysis, at which scale both the biophysical and the socio-economic variables were recorded. The spatial zoning of the HSs was performed using Thiessen polygons, an exact and deterministic interpolation method (Okabe & Suzuki 1997). In the sectors corresponding to each HS and its influence area, we recorded quantitative information referring to 64 socio-ecological descriptors: 12 climate variables (mean annual rainfall; mean annual temperature; mean rainfall and temperature for each of the four seasons; potential annual evapotranspiration; and continentality index), 10 geomorphological variables (Table 1), 11 vegetation and land-use variables (coastal vegetation; beaches, dunes and sandbanks; recent volcanic extrusions; agricultural lands; abandoned crops; shrubland; scarce vegetation; urbanized areas; coniferous plantations; ravines, willow groves and tamarisks with palms; orchards and greenhouses) and 31 socio-economic variables (employment by branch of activity, characteristics of housing and urban areas, population by place of birth, tourism lodging and cultural interest goods; Appendix S2).

The climate starting data, provided by the Spanish State Meteorology Agency, correspond to data from 1987 to 2007 at 30 meteorological stations (AEMET 2007), which were selected from a total of 48 according to the length of the series, temporal stability and density (spatial cover). The climatic variables were obtained by means of mixed extrapolation combining global statistical interpolation, multivariate regression and local residual

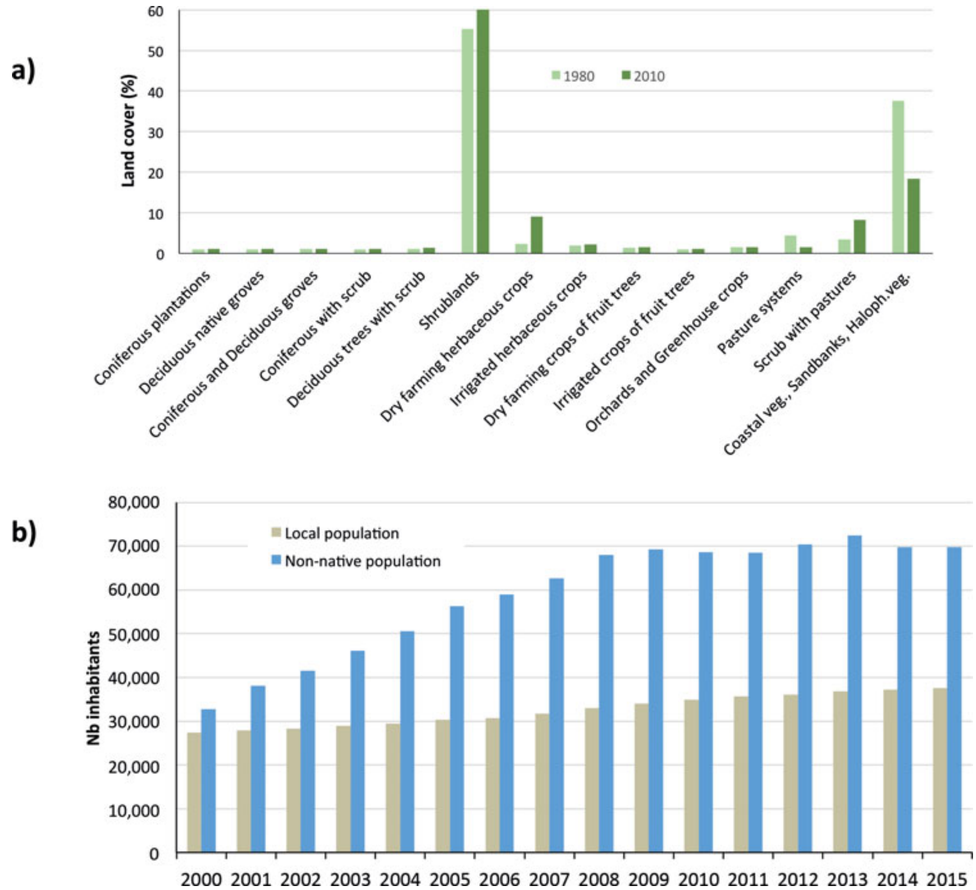

Figure 1 (a) Dynamics of vegetation and land uses of Fuerteventura (1980–2010). (b) Variations of the native and non-native populations (2000–2015). Haloph. = halophyte; Nb = number.

Table 1 Geomorphological variables used in the landscape analysis.

Variables	*Categories*
Altitude (m asl)	
Very low	0–112.93
Low	112.93–225.86
Medium	225.86–373.30
High	373.30–799.94
Slope (%)	
Slow	≤12 (agricultural soils)
Medium	>12 to ≤20 (soils with occasional cropping)
High	>20 (forest/scrub soils)
Hydric convergence (log number of tributary cells)	
Low	4.60–7.60
Medium	7.60–10.60
High	10.60–13.60

correction with spatial interpolation (Ninyerola *et al.* 2007a; Ninyerola *et al.* 2007b). Annual potential evapotranspiration and Thornthwaite continentality indices were calculated according to Rivas-Martínez and Rivas-Saenz (2009). Data on global radiation and insolation were obtained with the hemispheric visual basin algorithm (Fu & Rich 2000). Topography variables were treated with a digital terrain model and described according to the altitude, slope and hydric convergence of the terrain (Table 1). The resolution of climate and geomorphological variables was 100 × 100 m.

We recorded the percentage cover of each type of vegetation and land use in each influence area. The information was taken from maps of land and vegetation occupation at a scale of 1:25,000 (Arco 2008), which were validated by detailed field trips and sampling of plant communities. Biophysical variables were treated using the ArcGIS software (ESRI 2012). Socio-economic descriptors were obtained from statistical databases (ISTAC 2016).

Characterizing socio-ecological interdependences

Step 1: spatial assignment of socio-ecological descriptors

We assigned the environmental and socioeconomic descriptors to the HSs studied using two matrices of georeferenced quantitative data. The first described the small towns, villages and hamlets by means of biophysical variables, quantified as a percentage of the occupied area in each HS and its surrounding territory (Thiessen polygons). The second matrix contained the socio-economic characteristics assigned to the spatial units as a percentage of the value of each variable in each HS with respect to the total value of the same variable in the study area.

Step 2: quantifying socio-ecological webs – current scenario
We used a procedure based on Schmitz *et al.* (2003). In order to quantify the current relationship between biophysical characteristics and socio-economy, we performed a canonical correlation analysis (CCA) that allowed the relationship between the two variable sets to be examined (Sherry & Henson 2015). Taking into account the analytical requirements of normality and homoscedasticity, we standardized and $\log(x + 1)$ transformed the data, where x represents the value of each socio-ecological variable in the area surrounding each HS. We identified and mapped HS types by segmenting the CCA plane into five intervals using the natural break method, based upon the coordinates of the observations projected on the ordination plane (Ruiz-Labourdette *et al.* 2013).

Step 3: simulation of socio-ecological shifts under CC scenarios
We simulated socio-ecological changes in the future under four scenarios based on climate conditions predicted for the 21st century according to IPCC (2000). We used A1F1, A2, B1 and B2 scenarios with the HadCM3, a coupled atmosphere–ocean general circulation model (Collins *et al.* 2001). The adaptation of this global model to a regional scale was achieved through the downscaling performed by the Agencia Estatal de Meteorología (AEMET), with a resolution of $50 \times 50\,\text{km}^2$. For the Canary Islands, the downscaling was performed using statistical techniques, which use transfer functions to convert global-scale outputs to regional-scale conditions (Morata 2014). This is one of the most used tools in CC studies as it enables the construction and testing of scenarios (Wilby *et al.* 2002).

The four scenarios considered represent 68% of the range of uncertainty in emissions, as measured by cumulative carbon dioxide emissions (1990–2100), compared to the full set of 40 scenarios (IPCC 2000; Mitchell *et al.* 2004). Scenarios differed mainly in carbon predicted to be emitted from energy and industrial sources by 2100. The A1F1 scenario is highlighted by the intensive use of energy sources of fossil origin (an atmospheric CO_2 concentration of 30.3 Gt in 2100); the A2 scenario involves a semi-intensive use of fossil fuels (an atmospheric CO_2 concentration of 28.9 Gt in 2100); and scenarios B1 and B2 involve lower CO_2 emissions (an atmospheric CO_2 concentration of 5.2 Gt and 13.8 Gt in 2100, respectively).

The forecasts of climate variation (Table 2) for each of the scenarios (Mitchell *et al.* 2004) suggest greater aridification of the island and, therefore, substantial changes in vegetation distribution. This effect of CC involves the modification of some of the main descriptors of vegetation and land uses. The prediction of species responses to novel climates may be problematic due to the lack of observational data to determine their behaviour (Williams & Jackson 2007). Thus, predictions were based on literature reviews, considering real present-day tendencies in Fuerteventura, within reasonable variation thresholds, taking into account extreme values of the variables in the spatial units and the prediction limits of the model (Arco 2008; De Aranzabal *et al.* 2008). Using the results of the CC hypotheses for the Canary Islands as a basis, we designed four quantitative biophysical matrices, one for each scenario. In all four cases, the interdependence between these predicted biophysical data and socio-economic descriptors was analysed by CCAs, which provided the coordinates of the HSs on the axes describing the new socio-ecological structures derived from the scenarios. The analysed data fulfilled the basic assumptions of the CCA procedure concerning sample size issues, linearity and normality.

The comparison between the current CCA plane and those of the CC scenarios allows for the quantification of the socio-ecological change derived from CC. We considered the magnitude and direction of changes based upon the value and sign of the increments of the coordinates (Δ_{coord}) of the HS set represented on the CCA planes, calculated as the difference in the value of the coordinates in the CC scenario in relation to the present one. We assumed changes were significant when Δ_{coord} was $\geq$25% in relation to maximum Euclidean distance between the current and simulated scenarios. We used the results of CC simulation for mapping the potential socio-ecological configuration of Fuerteventura.

RESULTS

Socio-ecological characterization

The CCA axes (Fig. 2) were generated to yield the largest possible correlation between the variables. The first axis (variance explained: 32.94%) is the product of the maximum possible correlation between HSs and variable scores. It explains environmental variation along an altitudinal gradient from coast with beaches, dunes and halophyte vegetation to medium and high inland agricultural lands. The other components of the axis are the socio-economic variables showing a gradient related to local economic development. This process is linked to the structure of the local population that constitutes an active and traditional socio-economic system (positive end of the axis), and to a tourism system in which the native population has little representation (negative end of the axis). Non-native people are concentrated in tourism areas.

The second axis (variance explained: 14.85%) also has maximal site–variable correlation (Fig. 2), subject to the constraint that the axes are orthogonal. It again shows environmental variation derived from the altitudinal gradient, where low altitudes are occupied by urban development and the remnants of natural vegetation, while higher areas have scarce vegetation and agricultural systems show signs of abandonment. The local population is associated with a process of decline of agrarian-based activities ('deagrarianization') and with the recognition of cultural interest goods and the natural heritage of the rural areas ('patrimonialization'; positive end of the axis). The non-native population is nevertheless associated with urbanized areas (negative end of the axis). This spatial variation highlights

Table 2 Forecasts of climate variation for the four Intergovernmental Panel on Climate Change scenarios considered.

	A1F1	*A2*	*B2*	*B1*
Winter mean temperature	+2.9°C	+2.4°C	+1.8°C	+1.7°C
Winter mean rainfall	–6%	–5%	–3%	–3%
Spring mean temperature	+3.0°C	+3.2°C	+1.8°C	+1.6°C
Spring mean rainfall	–6%	–2%	–2%	–1%
Summer mean temperature	+3.0°C	+2.5°C	+1.8°C	+1.8°C
Summer mean rainfall	–3%	+3%	+2%	+10%
Autumn mean temperature	+3.0°C	+2.3°C	+1.7°C	+1.7°C
Autumn mean precipitation	–3%	–3%	–2%	–2%
Mean annual temperature	+2.98°C	+2.6°C	+1.78°C	+1.7°C
Mean annual rainfall	–4.5%	–1.75%	–1.25%	+1%
Continentality index	+0.1°C	+0.9°C	+0.1°C	+0.2°C
Potential annual evapotranspiration	+10%	+9%	+6%	+5%
Ravines with palms, willows, tamarisks	–15%	–15%	–10%	–10%
Beaches, dunes and sandbanks	–25%	–20%	–15%	–10%
Coastal vegetation	–30%	–25%	–20%	–15%
Abandoned crops	+15%	+20%	+10%	+10%
Agricultural lands	–25%	–25%	–15%	–15%
Scarce vegetation	+15%	+15%	+10%	+10%
Shrubland	+30%	+25%	+15%	+10%

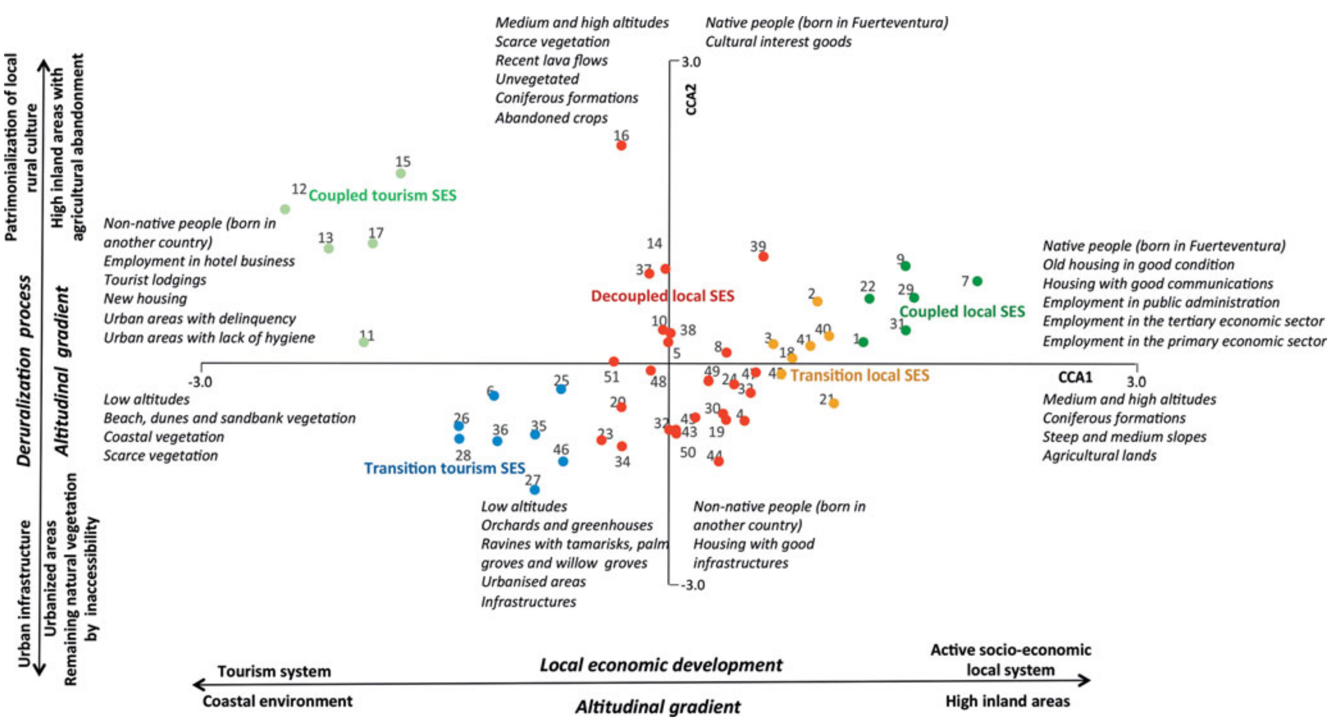

Figure 2 Scheme of the canonical correlation analysis (CCA) results in the current scenario. Biophysical and socio-economic variables with higher scores are indicated at the ends of the axes. Circles represent the human settlement types: coupled local socio-ecological systems (SESs; green); transition local SESs (orange); decoupled local SESs (red); transition tourism SESs (blue); and coupled tourism SESs (light green). Codes of the settlement numbers can be found in Appendix S1.

the loss of rural areas as significant socio-economic change occurred in Fuerteventura ('deruralization').

The optimal patterns of joint association between biophysical and socio-economic variables are defined by the ordination diagram. Thus, the analysis performed allows us to interpret the territory in terms of socio-ecological webs where human and biophysical systems are linked with different degrees of intensity and meanings. The results indicate the transition of Fuerteventura from a coupled local SES to a different type of coupled system derived from the interaction between the coastal environment and tourism. This new system implies the decoupling of local

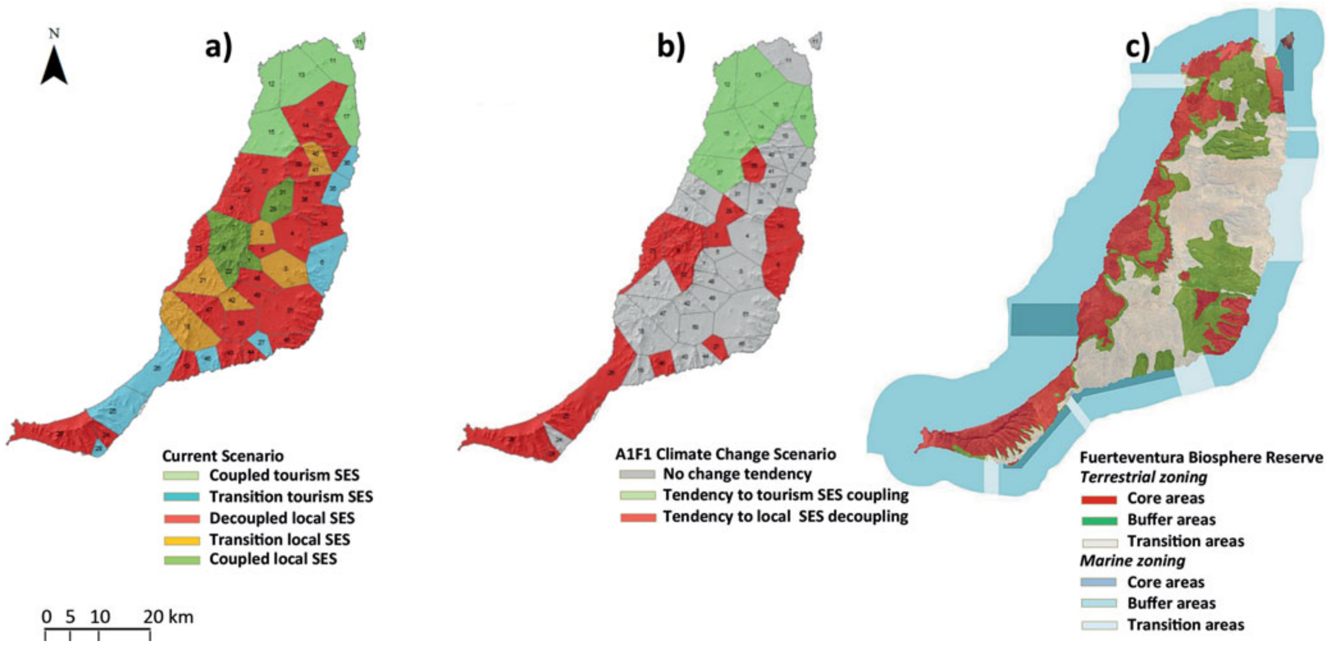

Figure 3 Mapping of the socio-ecological webs of Fuerteventura. (a) Current scenario; (b) climate change scenario (A1F1; Intergovernmental Panel on Climate Change); (c) Fuerteventura Biosphere Reserve. Codes of settlement numbers can be found in Appendix S1. SES = socio-ecological system.

people from their traditional environment. A segmentation of the ordination plane allows us to obtain five types of HSs according to their socio-ecological characteristics and degree of coupling (Fig. 2). At the right end of the ordination plane, we observe a first socio-ecological type characterized by a high degree of coupling ('coupled local SES'), in which the local population plays an important role. It is a group of HSs located in inland areas, where the local socio-economic system remains active. The socio-ecological characteristics of the second type of HSs denote a state of transition between rural coupling and decoupling ('transition local SES'). Rural decoupling is the main characteristic of the third socio-ecological type detected ('decoupled local SES'). This group encloses inland HSs subjected to rural abandonment and urbanization processes and occupied by non-native people. The remnant local population is related to the heritage valorization of traditional rural spaces. The fourth and fifth HS types ('transition tourism SES' and 'coupled tourism SES', respectively) represent final stages of the gradual transformation of rural areas into a tourism system that is mainly developed in coastal areas. This tourism expansion is related to non-native people and to social and environmental problems (Fig. 2).

Important parts of the areas that currently have decoupled traditional SESs belong to the core and buffer zones of the biosphere reserve and are particularly aimed at enhancing both the conservation of natural resources and the rural cultural landscape ('core areas' and 'buffer areas', respectively; Fig. 3).

Simulated changes in the SES

The planes of the CCAs applied to the data matrices of the four scenarios of the IPCC show the simulated socio-ecological structure according to the climatic scenarios. The CCAs of the current scenario and those of CC have similar ranges of variation (from –3.0 to 3.0), indicating that the present and simulated socio-ecological relationships are distributed in spaces of equal dimensions and are therefore comparable to each other (Figs 2 and 4). There is a similar displacement of the HSs in the four assumptions of change, although the intensity of change is more pronounced under the A1F1 scenario of high emissions (Fig. 4). In all situations, the displacement mainly affects SESs with a relative high coupling in the current scenario (coupled local SESs and coupled tourism SESs), and especially those that are linked to the tourism system, which change towards a greater degree of coupling (displacement towards the negative end of CCA axis 1; Fig. 4).

Regarding HSs characterized in the current scenario as coupled local SESs, their variation with CC is towards rural decoupling (displacement tendency towards the positive end of CCA axis 2; Fig. 4), characterized by deruralization and deagrarianization processes.

The change tendency in the socio-ecological typology under the A1F1 emission scenario of high emissions is towards north–south variation in socio-ecological decoupling. The CC intensifies the ongoing rural decoupling in the core and buffer areas of the biosphere reserve (Fig. 3), which have the highest degrees of protection and were specially designed to manage changes in SESs.

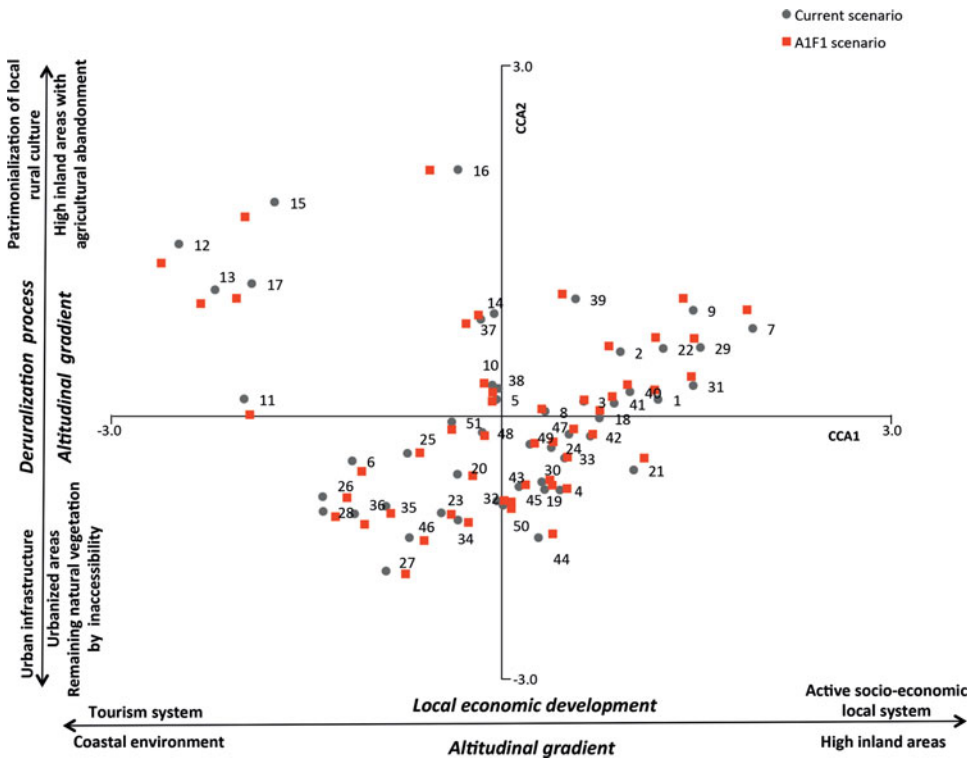

Figure 4 Canonical correlation analysis (CCA) plane of the socio-ecological changes simulated in Fuerteventura according to projected A1F1 Intergovernmental Panel on Climate Change scenario. Codes of settlement numbers can be found in Appendix S1.

DISCUSSION

The method developed allowed us to understand the functional connectivity between nature and human systems (socio-ecological webs) and to characterize the degree of socio-ecological coupling of each HS of Fuerteventura. The applied model is a simple tool that avoids the complexity involved in other models (Van Nes & Scheffer 2005). Its limitations are those inherent to the availability and resolution of environmental and socio-economic databases at the required scale. We use a multidimensional approach to analyse multiple ecosystem components at the same time. This allows for the definition of different states of the system and the quantification of the intensity of changes due to environmental shifts (Barros *et al.* 2016). Therefore, this numerical procedure permits the prediction of variations in SESs ('novel systems'; Williams & Jackson 2007) under realistic scenarios of CC, within the limits set by the restrictions of the model.

Although this study focuses on a specific area, the method can be extrapolated to other areas, since it allows for the quantification of the relationship between landscape and socio-economy of any territory. Similar procedures have been used to characterize the links between different types of structures, mainly in rural cultural landscapes (Schmitz *et al.* 2003; De Aranzabal *et al.* 2008; Schmitz *et al.* 2012), and to obtain variation models resulting from the simulation of CC scenarios (Ruiz-Labourdette *et al.* 2013).

In this island, natural capital provides minimal conditions for human survival and the extreme environmental conditions prevent high agricultural productivity (Fig. 1). Nevertheless, a rural culture emerged with a balanced relationship between people and nature on which the local economy depended. The cultural, ethnological and natural values of this SES were recognized with the establishment of the biosphere reserve.

Across the environmental gradients, the land uses and socio-economic characteristics of the inhabitants of the island vary (Fig. 2). The main socio-ecological gradient (first CCA axis) indicates the existence of both a coupled and socio-economically active local system, which preferentially occupies inland areas, where traditional productive activities persist, and a tourism system associated with coastal zones, where the local population is currently not well represented and has little participation in its management and governance. The rural–tourism contrast appears along the first CCA axis, characterizing the current socio-economic structure of Fuerteventura. The tourism industry has promoted significant economic and social change, involving the gradual transformation of traditional rural activities linked to the primary economic sector towards others based on the tertiary economic sector. Coastal zones are today the main tourist areas, many of which suffer from the typical impacts of tourism developments with weak management (impacts on hygiene, health and the internal structure of host communities; Butler 2006). The substitution of rural culture by tourism energizes the labour market and modifies the cultural heritage and historical identity (Antošová 2014). This process has greatly increased the dependence of the local economy on the tourism industry.

The second CCA axis reveals a significant socio-ecological gradient, which is consistent with the variation expressed by the former axis. Such redundancy is good, because some errors in measuring the environmental data may be averaged out (Palmer 1993). In this case, an altitudinal gradient from the coast to inland is related to deruralization, deagrarianization and urbanization processes, mainly for the residence of the non-native population, and patrimonialization of traditional rural culture and natural areas by the local population. Traditional land-use abandonment and urbanization are processes that are listed among the main pressures and threats to European habitats (European Commission 2016) and are related to the uprooting and eradication of rural spaces (Chesnais 2001). Urban expansion, deagrarianization and appreciation of natural and cultural rural goods (heritage valorization) are associated phenomena, being causes and consequences of the same process of change that leads to a new socio-cultural construction of patrimony and cultural heritage, where rural areas and local identity are fundamental determinants of territorial development (Sharpley & Jepson 2011). This is a frequent process in European rural areas, where the value of local heritage and territorial identity are taken into consideration in initiatives of support and programmes of the European Union (European Commission 2014). In the Canary Islands, initiatives have been promoted for managing heritage and establishing protected natural areas in an attempt to avoid planning errors that threaten island ecosystems (García-Rodríguez *et al.* 2016).

Cultural landscapes as world heritage elements were considered to be conservation opportunities for rural landscapes with exceptional values (Mitchell *et al.* 2009), but there has been abandonment or replacement of this approach by new economically competitive activities. The biosphere reserve has not prevented the decoupling of the secular relationship between human societies and nature in many areas of the island. This is not a unique case in relation to the establishment of protected areas (Schmitz *et al.* 2012).

We deduce that the Fuerteventura SES is composed of subsystems with different degrees of coupling: a strong human–environment interaction in a given subsystem can mean an intense decoupling for another. SESs are remarkably complex, dynamic and adjustable (Gual & Norgaard 2010; Reynolds *et al.* 2011) and can self-organize around different points or attractors (Biggs *et al.* 2012).

CC is today regarded as one of the main factors in the Fuerteventura SES that is modifying tourism trends due to its direct connection to nature and climate conditions (Hamilton & Tol 2004; Bujosa & Rosselló 2013). Island destinations are considered very vulnerable to climate impacts (Uyarra *et al.* 2005). Nevertheless, in this case, simulations conducted under four IPCC scenarios based on the available data show both a tendency to increase the decoupling of local systems and a greater coupling of tourism systems across the island (Figs 3a, 3b and 4). The projected trends in the climate parameters show accelerated warming and decreases of rainfall in the Canary Archipelago (García-Herrera *et al.* 2003; Martín *et al.* 2012). Fuerteventura exhibits a desert-like climate and vegetation. CC would cause greater aridity and an increase in the tendencies of deruralization. The predicted increases in the decoupling of local systems and the coupling of tourism systems could be interpreted as responses of the local economy to greater difficulties in effectively using natural resources and to increasingly favourable climatic conditions for tourism.

CONCLUSION

The method developed allows for the interpretation of Fuerteventura in terms of socio-ecological webs, which depend on an environmental gradient and associated economic development. In social terms, this process is expressed by the variation of the inhabitants' typology (from native local to non-native people). The local population is linked with the cultural and natural patrimonialization of rural areas, which is currently characterized by a deruralization process. Non-native people are associated with the tourism system. The Fuerteventura SES is composed of subsystems with different degrees of coupling. Tourism-coupled systems appear to be parallel to the local decoupling.

The establishment of a biosphere reserve seems not to have foreseen the decoupling of the secular relationship between human societies and nature in an island influenced by the tourism industry.

The IPCC scenarios that were tested according to our model indicate a tendency to increase both the decoupling of local systems and the coupling of tourism systems. It is noteworthy how CC intensifies the tendency to rural decoupling in the buffer and core zones of the biosphere reserve.

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Supplementary material

For supplementary material accompanying this paper, visit https://doi.org/10.1017/S0376892917000169

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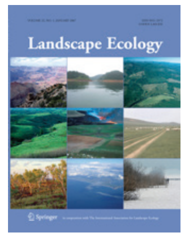
ARTÍCULO 05

Título: Aligning landscape structure with Ecosystem Services 1 along an urban-rural gradient. Trade-offs and transitions towards cultural services

Autores: Herrero-Jáuregui, C., Arnaiz-Schmitz, C., Herrera, L., Smart, SM., Montes, C., Pineda, FD., Schmitz, MF.



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Resumen:
Los gradientes urbano-rurales proporcionan un marco apropiado para estudiar la provisión de Servicios Ecosistémicos (ES) urbanos y rurales, vinculados al bienestar social. La estructura del paisaje (LS) cambia a lo largo de los gradientes urbano-rurales, pero pocos estudios muestran la relación entre la LS y los ES. Se evaluó la relación entre los cambios de la estructura del paisaje y los trade-offs o intercambios de ESs en el tiempo, a lo largo de un gradiente urbano-rural. Se consideraron dos fechas con un intervalo de más de 20 años (1990 y 2012). Un Análisis de Correspondencias Canónicas permitió identificar una marcada tendencia temporal de cambio hacia paisajes más heterogéneos, cuyos fragmentos presentan un bajo valor de conectividad entre ellos. Este cambio estructural está asociado con trade-offs de ESs. Se observó un claro intercambio de los servicios de provisión y regulación inherentes a los paisajes agrícolas y silvo-pastorales, a favor de los servicios turístico-culturales, demandados por la población urbana. Mediante un Modelo Lineal Generalizado se relacionó la intensidad del cambio del territorio con la magnitud del desarrollo urbanístico, la proximidad a una ciudad tan relevante como Madrid y las medidas de protección restrictivas vinculadas a los planes de conservación vinculados a la gestión supramunicipal del territorio. Los resultados obtenidos cuestionan la efectividad de las medidas de conservación a largo plazo tomadas en España para proteger los paisajes culturales rurales. Esto indica la necesidad de un cambio en la gestión de los Espacios Naturales Protegidos, que deben tener como prioridad el mantenimiento de las actividades tradicionales como potenciadoras del valor ecológico de los espacios naturales, fundamentales para el mantenimiento del flujo de servicios en gradientes urbano-rurales.

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-- Email del editor de Landscape Ecology --

From: Landscape Ecology (LAND) <em@editorialmanager.com>
Date: 2018-07-02 17:22 GMT+02:00
Subject: LAND-D-18-00095: Your Submission
To: Cristina Herrero Jáuregui <crherrero@bio.ucm.es>

Dear Dr Herrero Jáuregui,
We have received the reports from our advisors on your manuscript, "Aligning landscape structure with ecosystem services along an urban-rural gradient. Trade-offs and transitions towards cultural services:, which you submitted to Landscape Ecology. Based on the advice received, the Editor feels that your manuscript could be accepted for publication should you be prepared to incorporate minor revisions. When preparing your revised manuscript, you are asked to carefully consider the reviewer comments which are attached.

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Landscape Ecology

Landscape Ecology

Aligning landscape structure with ecosystem services along an urban-rural gradient. Trade-offs and transitions towards cultural services

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Abstract:	Context Urban-rural gradients provide an appropriate framework for studying the provision of urban and rural Ecosystem Services (ES), linked to social welfare. Landscape structure (LS) changes along urban-rural gradients but our understanding of the effects of LS on ES remains at an early stage. Objectives We assessed the relationship between changes in LS and ES trade-offs along an urban-rural gradient in Central Spain, and compared the intensity of change with the land conservation status, degree of urbanization and proximity to Madrid city. Methods We inferred the provision of ES at municipality level based on proxies from socio-economic data and land use maps, and characterized LS through metrics calculated from Corine land cover maps at two dates. We used Canonical Correspondence Analysis and Generalized Linear Models to analyse the data. Results

	There was a marked tendency for change in twenty years towards heterogeneous and poorly connected landscapes. This structural change appeared associated with trade-offs in ES, consisting of a loss of provisioning and regulating services inherent to agricultural and silvo-pastoral landscapes, in favor of tourist-cultural and accomodation services, recently demanded by a growing urban population. The intensity of this change was favoured by urbanization processes, the proximity to the city, and restrictive protection measures linked to supramunicipal land management conservation plans. Conclusions Our results question the effectiveness of long-term conservation measures taken in Spain to protect cultural landscapes. The innovative approach we use to analyze LS-ES coupling along urban-rural gradients provides a powerful tool for social-ecological land planning.
Response to Reviewers:	Responses to reviewers Reviewer 1 This is an interesting and useful paper showing the urbanisation process around Madrid. It would however be useful to include comparisons with other major cities to indicate possible solutions to the problem. For example Zurich and |Geneva have strict controls of new developments and do not have urban sprawl. My knowledge of Spain is that new building is not adequately controlled and new estates are often seen well away from existing urban areas. Thank you for your kind comment about the paper. Indeed, in Spain, and specifically in the study area, there is questionable territorial planning in some socio-ecological aspects. Following your suggestion, in the ms revised we have included a comparison with other European cities, in which the trend towards urban expansion is being reversed through corrective measures, following the guidelines proposed by the European Environment Agency (L. 464-467). We have also included comparisons with other Mediterranean areas (L. 439-440, 461-464). The paper should therefore be accepted with ‘minor corrections’ many of which I have indicated below and which can be included relatively easily. It would also be advisable to get an English editor to go through the text as there are a number of places where, for example-the definite article has been left out. I think Springer do this service. Thank you, an English colleague has revised the ms edition. Detailed comments The titles before all acronyms should have capitals eg It should be Ecosystem Services (ES) not ecosystem services. This applies to the Abstract and the main text—also note that the acronyms should be repeated again in the main text even if quoted before in the abstract. OK, it has been corrected as suggested. The acronyms ES have also been quoted in the introduction I do not know the policy of the journal but usually in scientific papers ‘we’ is not used--sentences should therefore be converted into non-personal words. Thank you for your comment. We checked papers in the last number of Landscape Ecology (v. 33) and many of them use this form as well (van Toor et al, Brehme et al, Martin et al, Brenan et al, West et al, Egerer et al, among others) Land use and land cover should be defined at the outset—they terms are often confused and are not interchangeable. Land use is for example: forestry, agriculture and recreation and land cover wheat, Scots pine forest and fertile grassland. OK, we have defined them in the introduction, and deleted the term land use from sentences in lines 211, 220, 235, 268, 272 and 287 of the old ms The numbers one to ten should be in letters and over 11 in numbers: this is not

consistent in the text.

We have corrected it except the numbers of tables and figures, that we maintain in numbers

L 84 remain does not need an s

Ok, corrected

L 114 remove –the conservation approach-and replace with 'planning controls' as these are probably causing the problems rather than conservation itself.

OK, corrected

L 117 change shrub to scrub—I have left shrublands later as it is a quote—shrub is an American not English term

OK, corrected

L135 change –is—to-- has been

OK, corrected

L150 replace –emplaced-with situated

OK, corrected

L165 I do not think that urban sprawl is promoted—it is only a result of lack of planning controls

We have reworded the sentence: "urban sprawl is probably linked to the lack of planning controls"

L 173 et seq the titles of the parks are in Spanish and should therefore be in italics

It has been corrected as suggested

L 195 IUCN not explained

Explained now in line 176: International Union for Conservation of Nature

L201 remove-allows knowing –and replace with—enables the understanding

OK

L 234 remove croplands as it duplicates arable but add-- woody crops as they are different and are important in the region

OK

L240 Is there much milk production and are there any toro bravo reserves?

Yes, there are some toro bravo reserves (linked to the, currently controversial, ancient tradition of bullfighting), and some milk production, but not many We have mentioned milk production here, but not toro bravo, as it is not for food provision. In this region mainly there is meat production.

L271—what are they pollinating---presumably woody crops such as almonds and peaches
In the area, the main crop production are cereals and woody crops. We have included it in the text (L. 277).

L350 what is nlme?

It is the name of the package and stands for “Linear and Nonlinear Mixed Effects Models”. We have added it to the text (L. 364)

L 374 many heterogeneous landscapes are well connected—it is necessary to explain why not in this region check also L414

We have clarified this aspect in the new ms. In the study area peri-urban and rural areas in transition from rural to urban systems show a highly fragmented and unconnected landscape linked to urban sprawl and land abandonment (Arnaiz-Schmitz et al. 2018). Lines 422-424 in the new ms.

L 420 I think dehesas should be mentioned earlier as they are so important and distinctive landscape elements
OK, we have mentioned and defined them in introduction (L 118-119). We have deleted previous definition from discussion.

L474 change where to were
OK

L476 add an s after population
OK

L480 This process is also occurring in the Picos de Europa National Park in North-West Spain
That is true, we have mentioned and quoted it (Bunce et al. 1998; Rescia et al. 2008). Lines 490-491 in the new ms

L 502 remove-vanishing and replace with-declining cultural
Thanks, we removed it

Reviewer 2: Very interesting and well written paper, focusing on trade off of ES vs Land use and land cover changes in peri-urban areas.

Only few limitations that could simply be improved.

1. Not all the important ES are examined for the examined topic. See for example: Manes et al, 2016. Regulating Ecosystem Services of forests in ten Italian Metropolitan Cities: Air quality improvement by PM10 and O3 removal, https://www.sciencedirect.com/science/article/pii/S1470160X16301133?via%3Dihub

Following your comment, we indicate in methods section the possible limitations of the procedure followed linked to the available data sets on an appropriate spatial scale (Lines 221-224 in the new ms).

2. literature is mainly focused on non-Med situations. A suggestion for analogue situation in mediterranean areas could be also:
MARCHETTI M. et al, 2014. Rural areas and urbanization: analysis of a change. Scienze del Territorio 4/2014, pp. 249-258. http://www.fupress.net/index.php/SdT/article/view/14333/13325

True, we have incorporated these references and others focused on Mediterranean areas (L. 440, 463-464)

3. A better discussion on the adoption of land cover as the best proxy of Landscape Structure is important, even because CLC has important limitations for these type of analysis, mainly due to its incoherent system of nomenclature and the scale of reference. See also:
Sallustio et al. (2016), Integration of land use and land cover inventories for landscape management and planning in Italy, Environmental Monitoring & Assessment (dic-2015), vol. 188 n. 1, pp. 20, DOI: 10.1007/s10661-015-5056-7

Thank you, we have included a couple of sentences discussing this issue (L. 314- 319

	in the new ms)

Aligning landscape structure with Ecosystem Services along an urban-rural gradient. Trade-offs and transitions towards cultural services

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Abstract

Context

Urban-rural gradients provide an appropriate framework for studying the provision of urban and rural Ecosystem Services (ES), linked to social welfare. Landscape structure (LS) changes along urban-rural gradients but our understanding of the effects of LS on ES remains at an early stage.

Objectives

We assessed the relationship between changes in LS and ES trade-offs along an urban-rural gradient in Central Spain, and compared the intensity of change with the land conservation status, degree of urbanization and proximity to Madrid city.

Methods

We inferred the provision of ES at municipality level based on proxies from socio-economic data and land use maps, and characterized LS through metrics calculated from Corine land cover maps at two dates. We used Canonical Correspondence Analysis and Generalized Linear Models to analyse the data.

Results

There was a marked tendency for change in twenty years towards heterogeneous and poorly connected landscapes. This structural change appeared associated with trade-offs in ES, consisting of a loss of provisioning and regulating services inherent to agricultural and silvo-pastoral landscapes, in favor of tourist-cultural and accomodation services, recently demanded by a growing urban population. The intensity of this change was favoured by urbanization processes, the proximity to the city, and restrictive protection measures linked to supramunicipal land management conservation plans.

Conclusions

Our results question the effectiveness of long-term conservation measures taken in Spain to protect cultural landscapes. The innovative approach we use to analyze LS-ES coupling along urban-rural gradients provides a powerful tool for social-ecological land planning.

Keywords

Land planning; Landscape metrics; Land use-land cover change; Protected areas; Social-ecological systems; Urban sprawl.

Introduction

The framework of urban-rural gradients is a socio-ecological approach widely used in landscape science to describe the relationships among land use (the physical land type) and land cover (the use given to the land) change, urban expansion and ecological and socio-economic dynamics (McDonnell and Pickett 1990; Kroll et al. 2012; Larondelle and Haase 2013; Radford and James 2013; Vizzari et al. 2018). These processes are the main driving forces of change in landscape structure (LS) impacting on the supply and demand of Ecosystem Services (ES), their trade-offs and synergies as well as the capacity of the ecosystems to achieve and maintain acceptable levels of social welfare (Arnaiz-Schmitz et al. 2018). Although several authors have studied the effects of the composition and configuration of landscapes on individual and multiple ES (Frank et al. 2012; Zhang and Gao 2016), our understanding of the effects of LS on ES remain at a very early stage (Eigenbrod 2016).

Worldwide, urban systems are the fastest growing land use type (Seto et al. 2012). The complex process of urbanization influences natural and cultural systems and is mainly characterized by the transformation of rural landscapes and their social fabric into urban ones (Antrop 2000). This urban-rural duality can be understood as a displacement of the degree of human influence from rural to urban landscapes, where urban areas play a large role in the economic context and in the flow of ES to society (McMichael et al. 2003; Modica et al. 2012). The gradual transformation of the countryside generates systems in urban-rural transition through a complex peri-urbanization process that, in most cases, makes the urban-rural limit difficult to identify (Arnaiz-Schmitz et al. 2018). This generates significant areas of land use transition where urban and rural activities are juxtaposed and landscape features are subjected to rapid human-induced modifications (Antrop 2000). In the urban-rural gradient, peri-urban areas and rural areas in urban transition are critical zones of land cover change characterised by mosaic systems of temporary and longstanding land uses. The comparison of ES provision in urban regions and their rural hinterlands can provide important evidence supporting the development of effective landscape planning and policy strategies. Therefore, at present, urban-rural gradients of ES are receiving increasing attention (Hou et al. 2015).

The ES supply depends largely on rural and urban ecosystem functions and, on that basis, it is vulnerable to human use, policy-oriented targets and landscape stewardship (Chapin et al. 2010; Wu 2013). In this sense, land use planning schemes include strategies to control and regulate urban development mainly based on the establishment of protected areas (PAs), especially designed to preserve biodiversity and ecological fluxes (Martín-López and Montes 2015). However, it is widely known that until recently and because of the accelerated transformation of natural and rural landscapes, the concept of "naturalness" has been the guiding principle of nature conservation goals and decision-making (Hobbs et al. 2010; Cole and Yung 2012). Usually these conservation schemes have been implemented through nature reserve networks with laws, policies or management that have caused many conflicts between the planning controls and urban development or the rural population demands, mainly due to the restrictions of access of local users to provisioning services (Gutman 2007; Martín-López et al. 2011; Schmitz et al. 2012). This has often caused rural abandonment, scrub encroachment and the loss of ES associated with a cultural landscape such as traditional *dehesa* systems (savannah-like landscapes with *Quercus* spp. or *Fraxinus angustifolia* alternating with hedgerows), in Central Spain (Schmitz et al. 2017). Furthermore, several studies highlight a significant urban sprawl process around PAs, which suggests that the presence of the PA is not effective in slowing the development of human settlements in their surrounding lands (Trzyna 2007; Arnaiz-Schmitz et al. 2018). Changing the management priorities of PAs is necessarily linked to social-ecological approaches related to the supply-demand of ES through them (Corbera et al. 2007; Gutman 2007).

The links between ES and social-ecological aspects have scarcely been considered in the context of urban-rural gradients, although the reciprocal interactions between land uses along such a gradient play a key role in the provision of services to humans (Burkhard et al. 2012; Maskell et al. 2013; Hou et al. 2015). In this paper we assessed the relationship between LS and changes in trade-offs and synergies among ES along an urban-rural gradient in the region of Madrid (Central Spain), and related the intensity of these changes to three characteristics of the urban-rural gradient: the conservation status at municipality level, the proximity to the main city and the degree of urbanization. The area is considered a European hotspot in urban development (Kuemmerle et al. 2016), in which, despite the establishment of a wide network of PAs, an accelerated dynamic of rurality loss and landscape homogenization has been observed (Schmitz et al. 2012, 2017; Arnaiz-Schmitz et al. 2018).

In summary, in this work we formulate the following hypotheses:

1) The provision of ES is coupled with changes in LS along urban-rural gradients.
2) The interaction between ES supply and LS changes over time.
3) The intensity of change of the ES supply-LS relationship is related to landscape factors that change along the urban-rural gradient, such as the land-protection status (PAs), proximity to the main city (Madrid), and the magnitude of the urbanization process.

Methods

Study area

The study area covers 2,535 km^2 of the region of Madrid (Central Spain) and includes 36 municipalities situated along a marked urban-rural gradient (Arnaiz-Schmitz et al. 2018) where altitude ranges from 400 m to 2,000 m asl (Fig. 1). The area has a continental Mediterranean climate with an average annual rainfall ranging from 700 mm to 800 mm. The average annual temperature ranges from 10-13°C. The north and west of the study gradient (33% of the area) is occupied by mountainous siliceous terrain and foothills with oak and pine forests, upland grasslands and silvo-pastoral systems. The centre and east (66% of the area) corresponds to the sedimentary basin of the Tagus River, which is traditionally associated with agricultural landscapes.

Until a few decades ago, the social-ecological systems of the area were still represented by a rural network of human settlements in which the main activities were linked to agriculture and livestock. Both silvo-pastoral and agricultural systems have historically supplied provisioning and regulating services to the city of Madrid. Nowadays, this territory, as in other European cultural landscapes, has undergone marked changes due to intense processes of urban growth, land use intensification and rural abandonment. Urban sprawl is probably linked to the lack of planning controls (Schmitz et al. 2012; Kuemmerle et al. 2016; Arnaiz-Schmitz et al. 2018). These processes have had important environmental, socio-economic and cultural consequences (Glaeser and Kahn 2004; Hortas-Rico and Solé-Ollé 2010).

Within this complex territorial matrix characterized by the urban-rural dichotomy, there are still vast areas with high natural and cultural values recognized at regional, national and international levels. One third of the study area comprises, in fact, a PA network: i) two Regional Parks ("*Cuenca Alta del Río Manzanares* Regional Park", created in 1985, and "Southeast Regional Park", created in 1994), a protection status recognized by the Madrid Regional Government similar to the International Union for Conservation of Nature (IUCN) VI protected area management category (IUCN 1994); ii) a National Park, created in 2013 ("*Sierra de Guadarrama* National Park"), declared of general interest by the Government of Spain because of its well-preserved natural sytems; iii) a Biosphere Reserve, created in 2005 ("*Cuenca Alta del Río Manzanares")* designed by the UNESCO's Man and the Biosphere Programme (MaB) and representing the integration of cultural and biological diversity, especially the role of traditional knowledge in the management of ecosystems; iv) six sites selected under the Nature 2000 Network (three Special Areas of Conservation for Birds, SPAs, and three Sites of Community Importance, SCIs).

Data collection

We focus on the provision of ES as a function of LS. We considered the municipalities as analytical units because they constitute the smallest unit of governance and therefore in the management of ES in the Madrid region and also the smallest level at which socio-economic and agricultural census data are available (Schmitz et al. 2012; Salvati and Serra 2016, among others). Thus, we considered descriptors of ES and landscape metrics at municipal level.

In order to quantify the intensity of change of the interactions between the provision of ES and LS, variables were assembled for two time points, 1990 and 2010. Most of this period has seen continuous economic growth, with few fluctuations until the economic crisis in 2008. We assume that, at landscape scale, the consequences of this crisis are perceived with a time-lagged response, thus they do not affect the temporal perspective considered here (Ramalho and Hobbs 2012).

Ecosystem Services

The ES framework enables an understanding of the conditions under which nature generates benefits to society. This approach is based on descriptors (indicators) (according to Margalef 1958; Lance and Williams 1966) that summarise the multiple dependencies of humans on the environment (Heink et al. 2016; Liquete et al. 2016). The purpose of the indicators is to measure and attribute values to ES. Nowadays, indicators for ES are based on a variety of data related to land cover, soil types, vegetation, nutrients, expert opinion and socio-economic variables, from local to global scales (Helfenstein and

Kienast 2014) and from rural to urban landscapes (Kroll et al. 2012; Larondelle and Haase 2013). Given the lack of empirical information about ES flows and how they are changing over time, researchers have been forced to consider proxy measures derived from empirical data or model-based methods which aim to capture states and trends on ES at meaningful scales (Haines-Young et al. 2012). Proxies are considered as approximations that represent the value of ES when they cannot be quantified. Because of the difficulty in measuring ES, scientists have tended to consider land cover as a proxy for the provision of services (Eigenbrod et al. 2010). Thus, the selection of suitable indicators to measure each ES is a key phase in ES assessments (Liquete et al. 2016).

In this paper the selection of ES indicators was carried out considering their sensitivity to land use change (Zipperer et al. 2000; Larondelle and Haase 2013). ES proxies used are restricted by the available data sets and the scale at which they are recorded. Thus data availability and data resolution constrain the extent to which the indicators can measure the ES-LS coupling (Manes et al. 2016). We inferred the provision of ten ES at municipal level, based on proxy indicators derived from socio-economic data and land use maps of 1991 and 2011. We selected valid proxies for provisioning, regulating and cultural services (Table 1). Proxies were selected according to available databases and their quantification has been conducted for the two periods selected. Number and spatial land occupancy were used as measurement units for the calculation of the amount of each ES at municipal level (Kroll et al. 2012; Baró et al. 2015). As indicated in Table 1, many of the indicators selected and estimated for provisioning and regulating ES are associated with types of land cover.

Selecting proxies of provisioning ES

Food provision. Directly related to agricultural land use, available arable land, woody crops, pasture systems, and livestock production (Metzger et al. 2006; Lautenbach et al. 2011). The area of pastures in the municipalities indicates potential forage production, defined as the provision of fodder for grazing domestic livestock (Reyers et al. 2009). Considering the current composition of livestock and the vegetation in each municipality, indicators of fodder production are correlated with the amount of meat and milk that could be produced hypothetically in the area (Kroll et al. 2012).

Water supply. Conservation of pasture systems, forests, wetlands and other natural or semi-natural habitats is essential to protect and enhance water quality (Polasky et al. 2012). One of the most valuable services provided by forest systems and grasslands is that of water supply. These type of ecosystems are key determinants of the quality of the water available for human use and play a crucial role in the local hydrological cycle, by reducing runoff and protecting soils from erosion and by storing runoff as groundwater or in wetlands, contributing to the service of water supply (Stenger et al. 2009; Ojea et al. 2012).

Selecting proxies of regulating ES

Bio-climatic regulation. The vegetation cover types and their relative condition classes strongly reflect the ecological functions of a landscape and its capacity to deliver a set of ES (Yapp et al. 2010). Forests systems are the source of a wide range of services, including the regulation of global temperature, precipitation, and other biologically mediated climatic process at global and local scales (Stenger et al. 2009). They participate in improving climatic conditions by actings as coolers and regulators of the air and temperature exchange (Gómez et al. 2001; Jim and Chen 2009). For this reason, we considered forests systems and wooded urban green areas as proxies of bio-climatic regulation services.

Water flow regulation and erosion control. Regulation of water flows and prevention of erosion are two closely linked ES. Water flow regulation is the storage component of the water services, which contribute to groundwater recharge (Egoh et al. 2011). Erosion control refers to the prevention of loss of soil by removal processes (Stenger et al. 2009). Appropriate land cover management allows reducing erosion and sedimentation processes, mitigating the risks associated with flooding (Bangash et al. 2013). Thus, forest water services regulate water flows, soil retention and a reduction in sediment loads (Corbera et al. 2007; Egoh et al. 2011; Ojea et al. 2012). Here we considered the relative contribution of land cover (forest, riparian vegetation strips and pasture) in regulating runoff, soil protection, sediment retention and water discharge (De Groot et al. 2002; Bangash et al. 2013) and thus in contributing to soil protection, water purification and the stabilisation of flow regimes (Stenger et al. 2009; Lautenbach et al. 2011).

Pollination. Animal-mediated pollination contributes to ES fluxes of value to humans. Our approach assumes that many species of free-living pollinator organisms from agricultural and natural habitats, in addition to the widely marketed European honey bee, contribute to crop pollination (in the area, mainly cereals and woody crops), providing a valuable service to local food producers (Chan et al. 2006). Pollinator organisms feeding within or between habitats and their dynamics are often affected by the spatial distribution of resources at the landscape scale (Kremen et al. 2007). Therefore, the provision of the pollination service depends on the distribution of pollinator nests, which can be estimated from the distribution of possible nesting habitats (Lautenbach et al. 2011). We estimated pollination service considering that pollinators tend to forage in the neighborhood of their nesting sites (Lonsdorf et al. 2009) and that changes in land cover are closely linked to alterations in pollinator communities (Kremen et al. 2007). Thus, we selected pollination proxies related to agricultural and natural settings, where crops and native plants can provide nesting or foraging sites (Allen-Wardell et al. 1998).

Selecting proxies of cultural ES

Outdoor recreation, leisure and tourism. Provision of recreational opportunities by the landscape. This concept values the function of ecosystems in providing opportunities for cultural and nature-based recreational activities. It considers different cultural goods provided by natural and semi-natural landscapes and other types of intangible or non material services linked to human perception, such as aesthetics experiences, spiritual enrichment, recreational values and cultural heritage (Vejre et al. 2010; Lautenbach et al. 2011; Peña et al. 2015). For instance, forest ecosystems, wooded lands, farmlands, green spaces in urban areas and other natural and semi-natural habitats supply numerous social and cultural services and represent a privileged place for outdoor recreation and leisure (Stenger et al. 2009; Baró et al. 2015; Komossa et al. 2018). We estimated the value of recreation, leisure and tourism in each municipality as a function of the amount of the described cultural goods and tourism recreational accommodation and facilities (De Aranzabal et al. 2009; Radford and James 2013).

Landscape structure

The delivery of many ES is dependent on their spatial context (Lautenbach et al. 2011). In this paper, the spatial structure of the landscape was characterized using landscape metrics, which are considered effective indicators of ecological systems for exploring causes and ecological meanings of landscape heterogeneity and their consequences on ES (Su et al. 2012, Syrbe and Walz 2012; Zhang and Gao 2016).

Landscape pattern metrics were calculated from Corine land cover maps (CLC) for the years 1990 and 2012 (Table 2). We considered seven land cover classes for the whole urban-rural gradient, namely: coniferous forests, broad-leaved forests, shrublands, grasslands, arable lands, urban and water bodies. To avoid possible confusions of nomenclature and reference scales in the information provided by CLC, the classes used were based on the reclassification of the CLC classes into more meaningful and representative categories according to the land use and dynamics of the region studied (Sallustio et al. 2016). Moreover, previous analysis in the study area using the same CLC data provided satisfactory results (Arnaiz-Schmitz et al. 2018). Landscape metrics were selected according to criteria based on their ability to describe landscape patterns, ease of interpretation, non-redundancy and comparability (Su et al. 2012). We used Fragstats (McGarigal and Marks 1995) for the calculation of the following landscape metrics: Shannon's diversity index (SHDI, quantifies landscape diversity and it is a good indicator of landscape heterogeneity), Shannon's evenness index (SHEI, measures the distribution of area among patch types; it is contrary to dominance), Patch richness (PR, measures the number of patch types present), Splitting index (SPLIT, measures the degree of the landscape fragmentation), Edge contrast index (ECON, a contrast metric that measures the magnitude of difference between adjacent patches), Euclidean nearest neighbour distance (ENN, describes the degree of spatial isolation of patches and, therefore, the degree of landscape connectivity) and Largest patch index (LPI, measures the size of patches and the amount of edge created by these patches and represents an indirect measure of landscape homogeneity) (Table 2). We generated a raster map of each of these metrics for the whole gradient, using a round moving window with a radius of 100 m, and then extracted a mean value for each metric in each of the 36 municipalities included in the study area.

Data analysis

We quantified the relationship between the provision of ES (constrained matrix) and the LS of each municipality (constraining matrix) in time, through a Canonical Correspondence Analysis (CCA). This analysis is used to determine the links between two or more sets of variables (Sherry and Henson 2005). We performed a stepwise permutation test to select the best model to account for ES provision. All analyses were carried out with the package Vegan 2.3-2 of R software (Oksanen et al. 2017).

We projected the coordinates of municipalities on the ordination plane and calculated the intensity of change over time by means of the displacement vectors, $\Delta\vec{D}_i$ (1), of the coordinates of each municipality on CCA axes (x, y, …n) from time t_1 to time t_2. The direction of $\Delta\vec{D}_i$ in relation to the reference CCA axis enabled us to determine the tendency of change of the provision of ES in relation to LS of each municipality (1).

$$\left\|\Delta\vec{D}_i\right\| = \sqrt{(x_{t2}-x_{t1})^2+(y_{t2}-y_{t1})^2+....+(n_{t2}-n_{t1})^2} \qquad (1)$$

This vector analysis enabled us to quantify the intensity of temporal change of the ES-LS interaction.

We used a Generalized Linear Model (GLM) to explain the response of displacement intensities. After checking for collinearity of several possible variables, we built the global model using predictor variables in each municipality associated to: i) the percentage of land belonging to established PAs, with different conservation categories and land-use restrictions according to national or European legislation. We included the *Sierra de Guadarrama* National Park that was established in 2013, after the period analysed here. Several thousand hectares of this nature reserve overlap with the Regional Park established in 1985 (Fig. 1); ii) the proximity to Madrid city; and iii) the percentage of urbanized land (Table 3). We used the "nlme" package in R to perform this analysis (Linear and Nonlinear Mixed Effects Models, Pinheiro et al. 2017).

In Table 3 there is a schematic description of the methodological procedure.

Results

Figure 2 summarises the results of the CCA. The plane shows the distribution of the municipalities according to the relevant ES and landscape metrics. The axes yield the largest possible correlation between the variables. The first one (variance explained 22 %) is the product of the maximum possible correlation between municipalities and variable scores. The second axis (11 %) also has maximal site-variables correlation, subject to the constraint that axes are orthogonal.

The first axis represents the main tendency of variation of the landscape pattern over time, from homogeneous areas with large patches (LPI on the positive end of the axis) to more heterogeneous and poorly connected landscapes characterized by their land use diversity and low connectivity between patches (SHDI and ENN land metrics respectively, on the negative end of the axis). Associated to the spatio-temporal change of the LS, this first dimension also expresses, from right to left, the change in time of the ES supply from provisioning services linked to agriculture (arable lands) to regulating services (water flows and air purification). The second axis shows, from bottom to top, a gradient from areas with numerous and different land use types (PR) supplying provisioning services (linked to livestock dominated landscapes) and regulating services (habitats for pollinator nesting sites), to landscapes with highly contrasted land uses, ECON, where the provisioning and regulating ES have been replaced by cultural ES, mainly represented by leisure and tourism infraestuctures.

The CCA plane reveals a marked tendency of LS change over time from homogeneous landscapes to more heterogenous systems. This change in the spatial pattern is associated with ES trade-offs based on a transition from provisioning and regulating services to cultural ones (Fig. 2).

The intensity of this change is positively related with the degree of urbanized land (Student's t-test = 2.40; $p < 0.023$) and the land area occupied by National Park (Student's t-test = 2.78; $p < 0.009$). However, it is negatively related to the distance to the main city (Student's t-test = -1.78; $p < 0.085$) and the land occupied by conservation and protection areas belonging to Nature 2000 network or Biosphere Reserves (Student's t-test = -3.50; $p < 0.001$). The protection status of Regional Parks is not a significant descriptor variable into the final model ($R^2 = 0.53$, $p < 0.001$; Table 5).

Discussion

The spectrum of landscapes spatially-nested along urban-rural gradients is generated from land use-land cover interactions of different types and intensities, which play a key role in the provision of ES to human population (Vizzari and Sigura 2015; Arnaiz-Schmitz et al. 2018). Few studies are based on the relationships between landscape patterns and ES (Anderson et al. 2009) and, often, spatial correlations between ES have been assumed, instead of being calculated (Chan et al. 2006; Boyd and Banzhaf 2007; Bai et al. 2011). In this paper we present a quantitative approach focused on the links between LS and ES provision along an urban-rural gradient, considering the influence of the distance to the main city, degree of urbanization and land protection status. Figure 3 summarizes the main landscape change tendencies over time detected in the study area.

The results support our three hypotheses. Firstly, we found that there is a close coupling of the ES-LS relationship along the urban-rural gradient studied. Traditional agricultural lands, with a homogeneous spatial expression, are associated with provisioning ES (crop production). Heterogeneous and patch-rich landscapessupply regulating (pollination, bio-climatic and water flow regulation) and provisioning (pasture systems and livestock production) ES (Fig. 3). Similar results have been found by Zhang and Gao (2016), whose study revealed consistent relationships between diversity metrics and regulating and provisioning services. In the region studied, peri-urban and rural areas in transition from rural to urban systems show a highly fragmented and unconnected landscape linked to urban sprawl and land abandonment (Arnaiz-Schmitz et al. 2018; see Fig. 3). These type of landscapes are mainly dedicated to silvo-pastoral activities, traditionally implemented in *dehesa* systems (Schmitz et al. 2012, 2017). This supports the high social-ecological value given to *dehesas* in maintaining biological diversity and cultural heritage (Pineda and Montalvo 1995).

Secondly, the ES-LS relationship is observed to change in time, as land use and land cover changes influence the evolution of landscape composition and configuration (Fig. 2). This result validates the sensitivity of the indicators considered to describe the land-use change in the study area (Zipperer et al. 2000; Kroll et al. 2012; Larondelle and Haase 2013). The temporal change observed indicates trade-offs between urban and rural demands, from provisioning and regulating services towards cultural services mainly demanded by urban population (Fig. 3). This process is associated with the gradual change of traditional landscape patterns to areas characterized by a heterogenoeous mixture of contrasted and poorly connected land use types, as has been found in other studies in the same region (Arnaiz-Schmitz et al. 2018) and other Mediterranean areas (Marchetti et al. 2014) . In the study area, the overall dynamic described is related to the general process of transition from primary to tertiary socio-economic sectors on the urban-rural gradient, essentially due to the increase in tourism (Antošová 2014; Schmitz et al. 2007). In Spain, this process is particularly relevant given the rapid abandonment of traditional rural activities and the depopulation of rural areas as a result of regional economic disparities, which have largely been-stimulated by many of the restrictions that the European Union has imposed on small scale productive activities (Baldock and Long 1998; Barrios and Strobl 2009; Palomo et al. 2013; Tirado et al. 2016).

Thirdly, the intensity of change in the ES-LS relationship (modules of displacement vectors) varies according to the proximity to Madrid city, the degree of urbanization and the status of protection. These three variables are, in turn, related to the urban-rural gradient considered here. Indeed, according to our results, the further away from the main city, the lower the magnitude of change (Table 5). Thus, the distance from, and accessibility to the metropolis are determining factors of the process studied (Antrop 2006). The degree of urbanization seems to be also one of the driving forces of change of the ES supply-LS interaction. It may be due to two processes. On the one side, the demand of cultural services by an expanding urban population fosters the transformation of traditional silvo-pastoral and agricultural landscapes. On the other side, urbanization of rural landscapes creates new and heterogeneous landscapes in the vicinity of towns and cities. Urban expansion and particulary urban sprawl are processes of singular interest in Spain and other Mediterranean countries, where a vertical pattern of urban growth has been replaced by a horizontal pattern characterized by a rapid, low-density outward expansion (Hortas-Rico and Solé-Ollé 2010, Romano and Zullo 2014, Marchetti et al. 2014). However, it is worth highlighting the fact that a renewed residential appeal and the increase in real estate activities in the central parts of cities can reverse this trend and favor a new gentrification, as is happening in some Swiss cities (Rérat et al. 2010), following the guidelines proposed by the European Environment Agency (EC 2006).

Finally, the influence of the land protection categories on the intensity of change of ES-LS interaction, clearly indicates a more efficient management of municipal land planning schemes than that of the supramunicipal ones, as other authors have highlighted (Palomo et al. 2014). Indeed, according to our results, municipal land planning that includes Nature

2000 network or Biosphere Reserves in their design, are more efficient at slowing down the rate of abandonment of primary to tertiary sector and thus maintaining provisioning and regulating ES. However, supramunicipal land planning schemes that manage Regional and National Parks have not been able to slow down the transition from provisioning and regulating ES to cultural services demanded by urban population as outdoor recreation or nature tourism (Fig. 3). This aspect has also been observed in other PAs in Spain (Martín-López et al. 2012). On the other hand, since the *Sierra de Guadarrama* National Park was established after the period analyzed here and its boundaries overlap with a wide extent of a Regional Park ("*Cuenca Alta del Río Manzanares*"), our results suggest that the National Park has been located in areas of more natural appearance, where rural activities were being actively abandoned. This questions the effectiveness of protection measures that impose restrictions of land uses and traditional rural activities, instead of promoting public policies to maintain rural populations and promote a highly valued cultural landscape with a greater potential to expand the supply of Ecosystem Services (Schaich et al. 2010). This misunderstood idea of preservation of nature, favours wilderness and naturalness instead of the high conservation values recognized in cultural landscapes (Plieninger 2006; Petanidou et al. 2008, Schmitz et al. 2017) as has been demonstrated in other protected areas of the region, such as *Picos de Europa* National Park (Bunce et al. 1998; Rescia et al. 2008).

Conclusion

Landscape spatial configuration, resulting from complex biophysical and social interactions, has a significant influence in the delivery of ES to human society. Therefore, changes in the landscape spatial patterning can affect the ES supply. This paper illustrates a quantitative approach developed in a social-ecological framework and focused on understanding linkage and dynamics of the ES-LS relationship along an urban-rural gradient.

Results of this study show a close coupling between LS, based on land use metrics as effective spatial indicators, and the supply of ES. Traditional homogeneous agricultural landscapes are associated with provisioning services, while heterogeneous landscapes, mainly represented by silvo-pastoral systems, are related to both provisioning and regulating services. There has been an evident structural change over time, from spatially homogeneous landscapes to more heterogenous ones, which, in terms of ES supply, has meant trade-offs from provisioning and regulating services to cultural ES demanded by urban population (Fig. 3). The intensity of change of ES-LS interactions is favoured by the magnitude of urbanization process, proximity to Madrid city, and restrictive land protection measures, usually implemented through conservation schemes managed at supramunicipal levels.

Our results highlight the need for land planning focused on cross-scale management of social-ecological systems and their ES supply to conserve declining cultural rural landscapes. Understanding the ES-LS spatio-temporal relationship provides unique information to support the development of more effective options to guide landscape planning and land use governance, predict landscape future trends and facilitate the integration of social-ecological goals onto political-economic decision-making.

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Figure captions

Figure 1. Location of the study area in Madrid Region (Central Spain). Municipal boundaries, Protected Area networks, human settlements and main motorways and highways are shown.

Figure 2. CCA plane showing the distribution of municipalities of the urban-rural gradient studied and their change in time (municipalities corresponding to each code are indicated in Appendix 1). Axes represent gradients of spatial pattern variation associated with ecosystem services (ES) trade-offs. ES proxies and landscape metrics with the highest scores are indicated at the end of the two axes. Grey points correspond to municipalities in t_1, and orange points to municipalities in t_2. Dashed arrows indicate the direction and intensity of change of each municipality. The curved arrow represents the main tendency of change on the ordination plane of the ES trade offs and landscape structure in time.

Figure 3. Graphic scheme summarizing the main tendencies of landscape change in the study area over time, based on landscape structure (LS) and ecosystem services (ES) interactions. Sizes of the color shapes indicate the predominant ES supply in the different landscape contexts detected along the urban-rural gradient. Green, regulation; orange, provisioning and blue, cultural ES demanded by urban population

Figure1

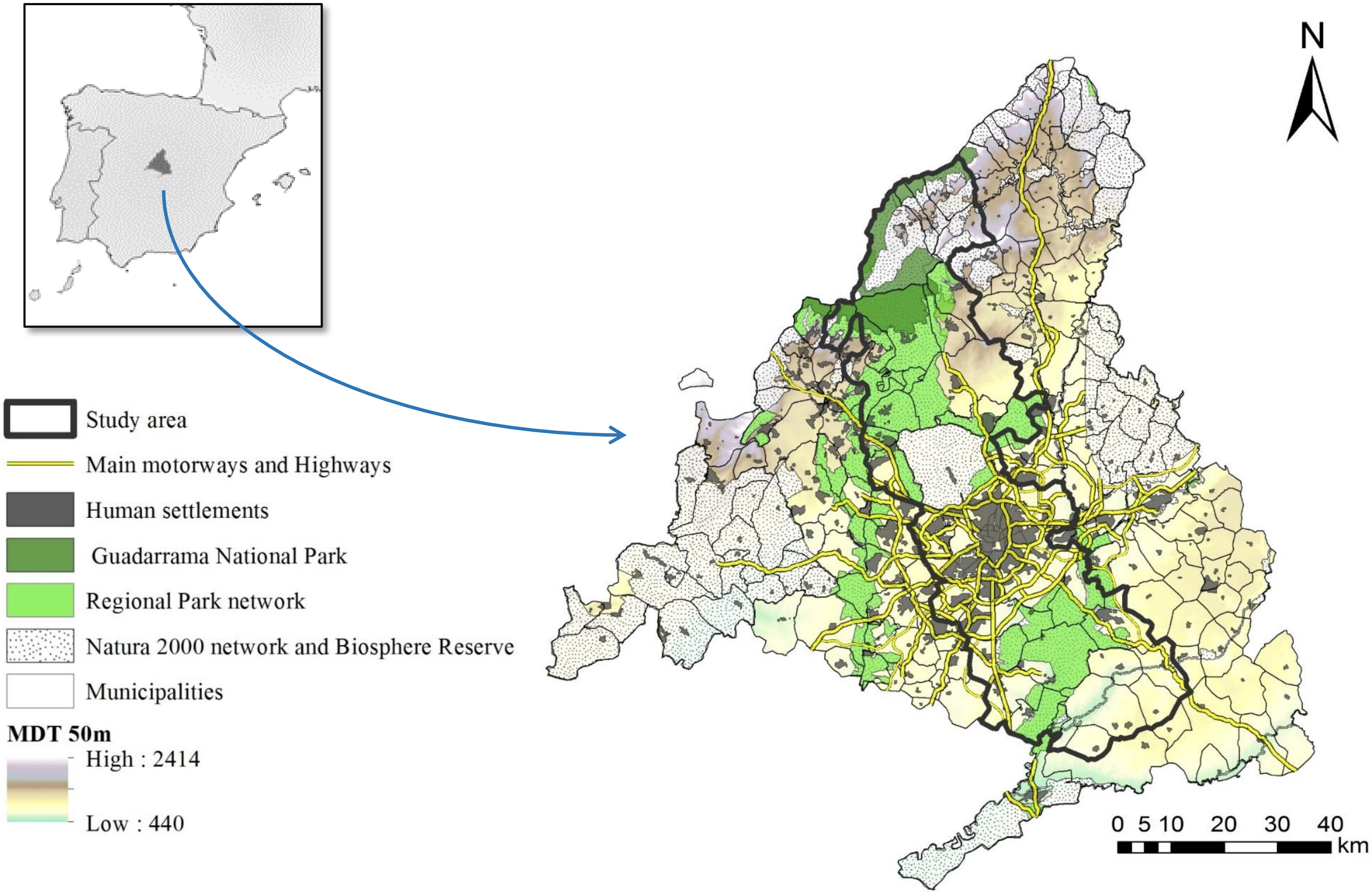
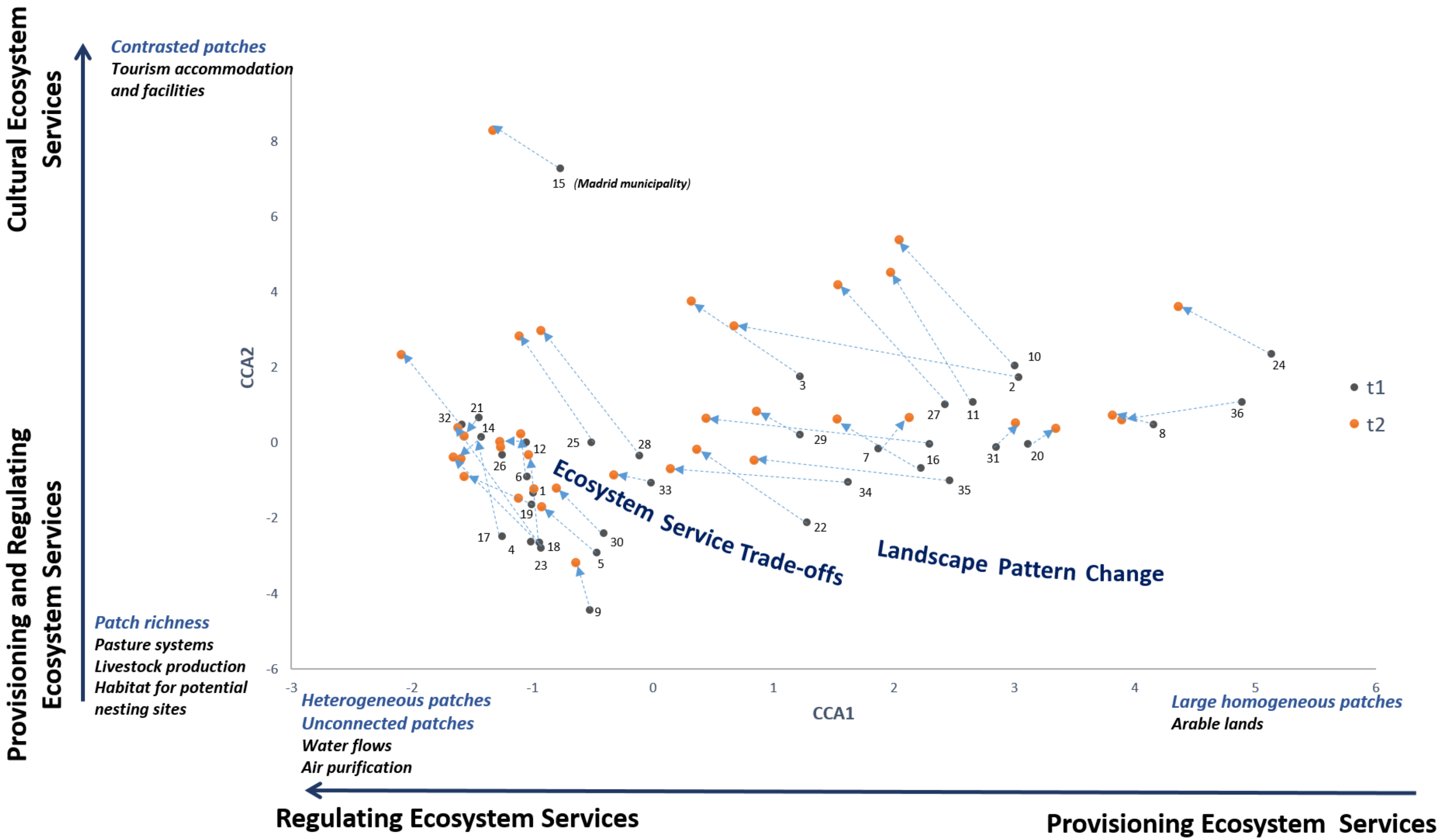

N
0 5 10 20 30 40
km
Study area
Main motorways and Highways
Human settlements
Guadarrama National Park
Regional Park network
Natura 2000 network and Biosphere Reserve
Municipalities
MDT 50m
High : 2414
Low : 440

Figure2



Cultural Ecosystem Services
Provisioning and Regulating Ecosystem Services
Contrasted patches
Tourism accommodation and facilities
Patch richness
Pasture systems
Livestock production
Habitat for potential nesting sites
CCA2
CCA1
15 (Madrid municipality)
Ecosystem Service Trade-offs
Landscape Pattern Change
t1
t2
Heterogeneous patches
Unconnected patches
Water flows
Air purification
Large homogeneous patches
Arable lands
Regulating Ecosystem Services
Provisioning Ecosystem Services

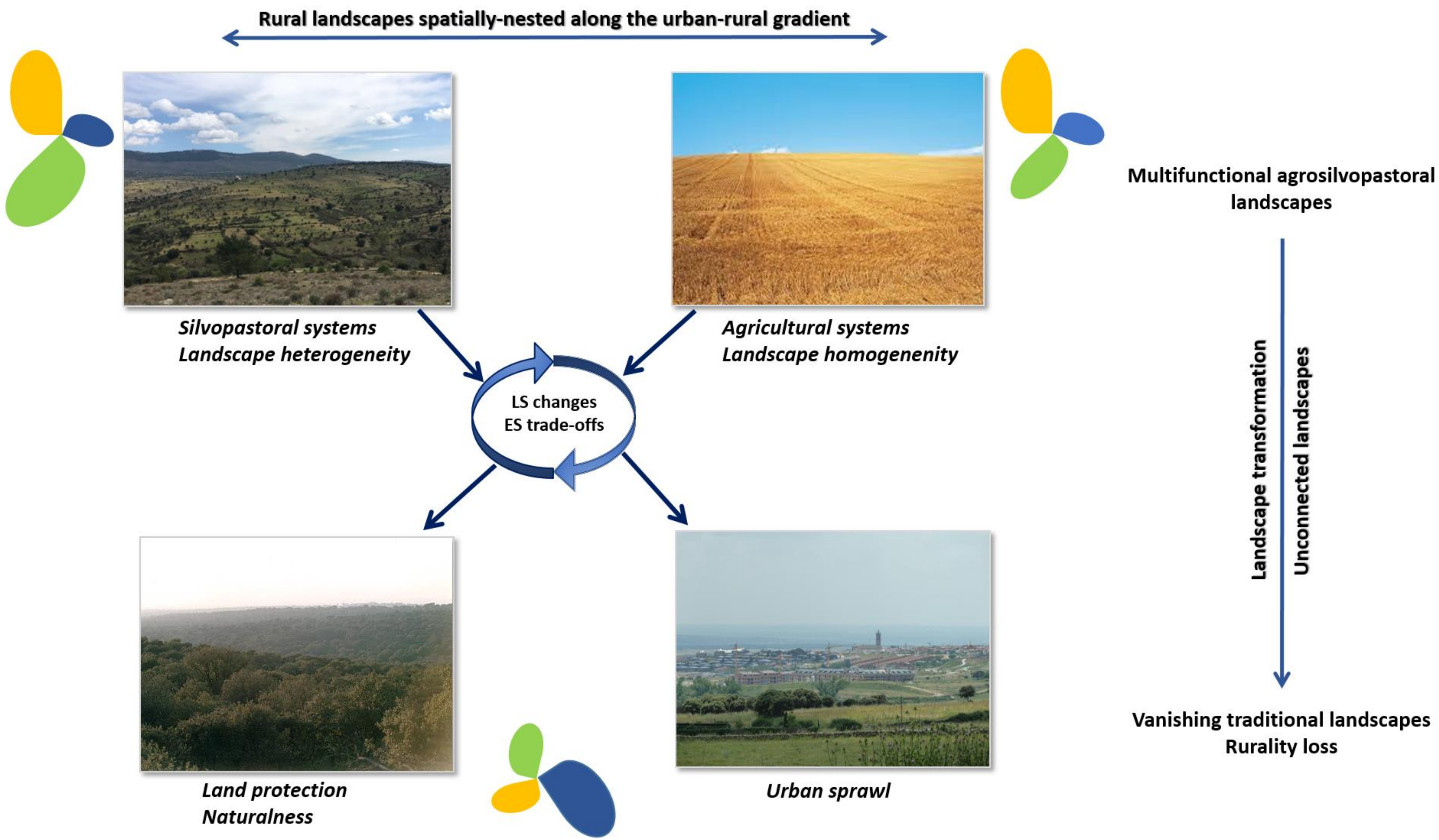

Rural landscapes spatially-nested along the urban-rural gradient
Silvopastoral systems
Landscape heterogeneity
Agricultural systems
Landscape homogenenity
LS changes
ES trade-offs
Land protection
Naturalness
Urban sprawl
Multifunctional agrosilvopastoral landscapes
Landscape transformation
Unconnected landscapes
Vanishing traditional landscapes
Rurality loss

Table 1. Selected proxies for provisioning, regulating and cultural ecosystem services. For each indicator a brief description, source of information and some relevant examples in the literature are indicated. Variables were quantified either as number or as percentage of occupied area, in both cases at the municipal level. Data were obtained from publics databases. INE: National Statistics Institute; SIGA: Geographic Information System of Agrarian Data; IECM: Statistics Institute of Community of Madrid.

Ecosystem services		Proxies	Definition	Source	Examples in literature
Provisioning	Food provision	Arable lands	Agricultural land for crop production. (Percentage)	INE 1989-2009	Metzger et al. (2006) Lautenbach et al. (2011) Kroll et al. (2012)
	Food provision	Pasture systems (production of forage for domestic livestock)	Permanent pastures in agricultural areas. (Percentage)	INE 1989-2009	Reyers et al. 2009 Kroll et al. (2012)
	Food provision	Livestock production	Cattle, sheep and pigs. (Number of animals)	INE 1989-2009	Egoh et al. (2011) Baró et al. (2017)
	Water supply	Freshwater availability	Forest systems (coniferous, riparian and deciduous forests). Pasture systems. Wetlands and reservoirs. (Percentage)	SIGA 1989-2010	Stenger et al. (2009) Egoh et al. (2011) Ojea et al. (2012) Polasky et al. (2012)
Regulating	Bio-climatic regulation	Air purification	Forest systems (coniferous, riparian and deciduous forests). Wooded urban green areas. (Percentage)	SIGA 1989-2010	Gómez et al. (2001) Jim and Chen (2009) Syrbe and Walz (2012)
	Water flow regulation	Water flows (water purification, storm protection, flood control, natural irrigation and drainage)	Forest systems (coniferous, riparian and deciduous forests). Pasture systems. (Percentage)	SIGA 1989-2010	De Groot et al. (2002) Corbera et al. (2007) Stenger et al. (2009) Egoh et al. (2011) Lautenbach et al. (2011) Ojea et al. (2012) Bangash et al. (2013)

	Erosion control	Soil and sediment retention, dredging and water quality	Shrublands, grasslands, meadows, deciduous and coniferous forests. (Percentage)	SIGA 1989-2010	Egoh et al. (2011) Stenger et al. (2009) Bai et al. (2011) Bangash et al. (2013)
	Pollination	Habitat for potential nesting sites	Croplands, shrublands, deciduous and riparian forests. (Percentage)	SIGA 1989-2010	Allen-Wardell et al. (1998) Chan et al. (2006) Kremen et al. (2007) Lautenbach et al. (2011)
Cultural	Outdoor recreation	Cultural goods	Monuments, museums, natural and cultural heritage sites, natural and semi-natural landscapes and other cultural goods. (Number)	IECM 2006-2012 SIGA 1989-2010	Stenger et al. (2009) Vejre et al. (2010) Lautenbach et al. (2011) Peña et al. (2015) Baró et al. (2017) Komossa et al. (2018)
	Leisure and tourism	Tourism accommodation and facilities	Places in tourism infrastructures and recreational facilities. (Number)	INE, 2004-2012	De Aranzabal et al. (2009) Radford and James (2013) Peña et al. (2015)

Table 2 Landscape metrics used to calculate landscape patterns. A brief description of each metric and its method of calculation are indicated.

Landscape metrics	Formula	Range	Description
Shannon's Evenness Index	$SHEI = \frac{-\sum_{i=1}^{m}(P_i \ln P_i)}{\ln m}$ P_i = proportion of the landscape occupied by patch type (i) m = number of patch types (i) present in the landscape, excluding the landscape border if present	SHEI > 0, without limit	SHEI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion, divided by the *ln* of the number of patch types (the observed Shannon-Wiener's Diversity Index divided by the maximum Shannon-Wiener's Diversity Index for that number of patch types)
Shannon's Diversity Index	$SHDI = -\sum_{i=1}^{m}(P_i \ln P_i)$ P_i = proportion of the landscape occupied by patch type (i)	SHDI > 0, without limit	SHDI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion
Patch richness	PR = m m = number of patch types present in the landscape	PR ≥ 1, without limit	Number of different patch types present within the landscape boundary
Splitting index	$SPLIT = \frac{A^2}{\sum_{j=1}^{n} a_{ij}^2}$ a_{ij} = area (m^2) of patch ij A = total landscape area (m^2)	1 ≤ SPLIT ≤ number of cells in the landscape squared	Increases as the landscape is increasingly subdivided into smaller patches and achieves its maximum value when the landscape is maximally subdivided; that is, when every cell is a separate patch
Edge Contrast Index	$ECON = \frac{\sum_{k=1}^{m}(p_{ijk} \times d_{ik})}{P_{ij}} \times (100)$ P_{ijk} = length (m) of edge of patch ij adjacent to patch type (k) d_{ik} = dissimilarity (edge contrast weight) between patch types i and k P_{ij} = length (m) of perimeter of patch ij	0 ≤ ECON ≤ 100	This index is a relative measure of the amount of contrast along the patch perimeter
Euclidean nearest neighbour distance	$ENN = h_{ij}$ h_{ij} = distance (m) from patch ij to nearest neighboring patch of the same type (class), based on patch edge-to-edge distance, computed from cell center to cell center		Distance (m) to the nearest neighbouring patch of the same type, based on shortest edge-to-edge distance. Has been used extensively to quantify patch isolation
Largest Patch Index	$LPI = \frac{Max\ (a)}{A} \times (100)$ a_{ij} = area (m2) of patch ij A = total landscape area (m^2)	0 < LPI < 100	Percentage of the total landscape comprising the largest patch

Table 3. Schematic description of the methodological procedure and explanatory variables used in the Generalized Linear Model.

<table>
<tr><th>Hypotheses</th><th colspan="2">Methods</th></tr>
<tr><td>The provision of ES changes according to landscape structure along an urban-rural gradient</td><td colspan="2" rowspan="2">CCA analysis of ES constrained by landscape metrics using both data matrices in two times

Stepwise permutation test</td></tr>
<tr><td>The provision of ES changes in time (two decades) in relation to changes in landscape structure</td></tr>
<tr><td rowspan="7">The intensity of change of the relationship between the provision of ES and landscape structure of municipalities might be related to the conservation status, proximity to the main city (Madrid), and the degree of urbanization</td><td colspan="2">Vector analysis of the coordinates of the municipalities on CCA plane (displacement vectors between t_1-t_2)

Generalized Linear Model with explanatory variables:</td></tr>
<tr><td>Explanatory variables</td><td>Description</td></tr>
<tr><td>Proximity to the main city</td><td>Distance from the centre of each municipality to the centre of Madrid city by the fastest way (km)</td></tr>
<tr><td>Protected areas</td><td>Land occupied by a National Park in each municipality (percentage). See methods</td></tr>
<tr><td></td><td>Land occupied by a Regional Park in each municipality (percentage)</td></tr>
<tr><td></td><td>Land occupied by conservation areas under the Nature 2000 network (Special Areas of Conservation for Birds –SPAs–, Sites of Community Importance –SCIs), or Biosphere Reserves in each municipality (percentage)</td></tr>
<tr><td>Urbanization</td><td>Land occupied by urbanized areas in each municipality (percentage)</td></tr>
</table>

Table 4. Scores of ES proxies and landscape metrics obtained from the CCA after the stepwise permutation test (all constraining variables are significant at $p < 0.05$). Variables with greater weights are indicated in bold.

ES proxies (constrained matrix)	**CCA1**	**CCA2**
Air purification	**-0.35**	0.09
Arable lands	**0.83**	0.09
Cultural goods	-0.07	0.16
Freshwater availability	-0.25	0.10
Habitat for potential nesting sites	0.15	**-0.13**
Livestock production	0.11	**-0.13**
Pasture systems	-0.21	**-0.29**
Soil and sediment retention	-0.20	0.11
Tourism accommodation and facilities	-0.16	**0.52**
Water flows	**-0.40**	0.26
Landscape metrics (constraining matrix)	**CCA1**	**CCA2**
Edge contrast index (ECON)	-0.33	**0.59**
Euclidean nearest neighbour distance (ENN)	**-0.50**	-0.23
Largest patch index (LPI)	**0.40**	0.02
Patch richness (PR)	-0.25	**-0.69**
Shannon-Wiener's diversity index (SHDI)	**-0.80**	0.18

Table 5. Generalized Linear Model used to explain the intensity of change of ES in landscapes of varying configuration ($R^2 = 0.53$, $p < 0.001$).

Model parameters

Variables	Value	Standard error	Student's t-test	Pr > |t|
Interception	2.737	0.621	4.408	0.000
Urbanized land	0.029	0.012	2.400	0.023
Proximity to Madrid	-0.015	0.008	-1.779	0.085
Nature 2000 network and Biosphere Reserves	-0.233	0.067	-3.498	0.001
National Park	0.827	0.298	2.779	0.009
Regional Park	0.000	0.000		

Model equation:

Intensity of change = 2.74 + 0.029*Urbanized land - 0.015*Proximity to Madrid – 0.23*Nature 2000 and Biosphere Reserve + 0.83*National Park

ARTÍCULO 06

Título: Evaluating the role of a protected area on hedgerow conservation: the case of a Spanish cultural landscape.

Autores: Schmitz, M. F., Herrero-Jáuregui, C., Arnaiz-Schmitz, C., Sánchez, I. A., Rescia, A. J., Pineda, F. D.

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Resumen:
Los setos son elementos clave en los paisajes agrícolas que realizan importantes funciones desde el punto de vista económico y ecológico. En este artículo, se cuantifica el cambio experimentado a lo largo de una década por una red relicta de setos localizada en un paisaje cultural del centro de España (Sierra de Guadarrama en el norte de la región de Madrid), tanto dentro como fuera de los límites de un Espacio Natural Protegido, entre cuyos objetivos se encuentra el de conservar los usos culturales y la biodiversidad. En el área de estudio se detectó un gradiente temporal de abandono y pérdida de los sistemas de pasto y de la red de setos asociados, así como un incremento de los procesos de matorralización. Las tendencias de cambio de paisaje detectadas fueron similares dentro y fuera de los límites del espacio protegido. Los resultados resaltan cierta ineficacia en la gestión de la reserva natural para lograr sus objetivos. En base a los resultados obtenidos, se propone incluir un estado de conservación específico para los paisajes de setos en el marco regulatorio de las áreas protegidas españolas.

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EVALUATING THE ROLE OF A PROTECTED AREA ON HEDGEROW CONSERVATION: THE CASE OF A SPANISH CULTURAL LANDSCAPE

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ABSTRACT

Hedgerows are key features in agricultural landscapes performing diverse functions that are both economically and ecologically significant. Here, we quantify how the characteristics of a relict hedgerow network of a Spanish cultural landscape (Guadarrama mountains in the north of Madrid region) have changed over a single decade both inside and outside the boundaries of a Protected Area, the aim of which is to conserve cultural uses and biodiversity. A gradient of abandonment of pasture systems was detected, including a decline and loss of woody species from hedgerows associated with grazed areas towards shrub encroachment zones. These tendencies were similar inside and outside the boundaries of the Protected Area. The results highlight the management weaknesses of the Protected Area in order to achieve its objectives. Based on the results, we propose to include a specific conservation status for hedgerow landscapes in the regulatory framework of Spanish protected areas. Copyright © 2016 John Wiley & Sons, Ltd.

KEY WORDS: habitat loss; landscape connectivity; management weaknesses; species richness; traditional management

INTRODUCTION

Land degradation is a consequence of the mismanagement of the natural resources. Usually, the abuse or misuse of those resources is because of agriculture, grazing, or mining (Bruun *et al*., 2015; Masto *et al*., 2016; Zhang *et al*., 2016). However, the human activities can be sustainable and some strategies as mulching, cash crops, low intensity grazing, or organic farming can help to achieve the sustainability (Costantini *et al*., 2015; Li *et al*., 2016; Lu *et al*., 2015; Prosdocimi *et al*., 2016). Hedgerows contribute to improve the land management as they imitate nature strategies such as the patchy or strip plant covers (Bochet, 2015; Cerdà, 1997a; Certini *et al*., 2015). They have been recognised as valuable habitats for a variety of wildlife as they provide refuge and food resources for many species, some of them threatened, or rare species of high conservation status (Dover & Sparks, 2000; Wilson, 1979). Frequently, they form contiguous networks of woody vegetation across landscapes and exert major controls on landscape fluxes, contributing to landscape connectivity (Baguette *et al*., 2000; Burel & Baudry, 1995; Davies & Pullin, 2007; Forman & Baudry, 1984; Hanski *et al*., 2000; Staley *et al*., 2012; Wehling & Diekmann, 2009) and preserving and sustaining rural biodiversity (Boughey *et al*., 2011; Bradbury *et al*., 2000; Hinsley & Bellamy, 2000; Merckx *et al*., 2010; Walker *et al*., 2005). Hedgerows are, in fact, significant components of cultural landscapes worldwide. They are also relevant elements at the local scale (Jongman & Smith, 2000), where they play a key role in protecting soils, reducing erosion, and preserving their vital function for food security, health, water security, and biodiversity (Keesstra *et al*., 2016). Hedgerows are traditionally managed to serve as field boundaries and windbreaks, improve crop productivity, reduce pest incidence (Morandin *et al*., 2014), provide shelter and forage for livestock (Baudry *et al*., 2000), and supply a wide variety of ecosystem services (Burel & Baudry, 1995; Busck, 2003; Forman & Baudry, 1984; Forman & Godron, 1986). Hedges also act as buffer strips that reduce the movement of sediment, nutrients, and pesticides from agricultural land (Novara *et al*., 2013). Soil sustainability being an interdisciplinary issue, the management of hedgerows forms part of the EECCD (European Economic Community Council Directive) (1991), where multiple stakeholders must be involved (Brevik *et al*., 2015).

In spite of their recognised importance, large-scale losses of hedgerows have occurred over the last half-century in many regions, as a result of both agricultural intensification and rural abandonment (Boughey *et al*., 2011; Schmitz *et al*., 2007). The removal or abandonment of hedges as a consequence of the loss of traditional management has significant effects on landscape biodiversity. Therefore, in many places there is a legal protection of hedgerows (Baudry *et al*., 2000). In Denmark, for example, hedgerows have been planted with public subsidies since 1880 (Langeveld & Röling, 2006) and German law has protected hedges since 1953 (Lekan & Zeller, 2005). More recently,

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the EU Biodiversity Strategy has designated hedgerows a priority habitat for conservation (JNCC (Joint Nature Conservation Committee)-DEFRA (Department for Environment, Food and Rural Affairs), 2012) and many Agri-Environment Schemes (AES) recognise the ecological importance and vulnerable conservation status of hedgerows and offer financial incentives for the creation of an environmentally sensitive hedgerow management (Boughey *et al*., 2011; Fuentes-Montemayor *et al*., 2011). Specifically in UK, where hedgerows have great cultural and landscape importance (Graham, 2012), the Hedgerows Regulations (DEFRA (Department for Environment, Food and Rural Affairs), 1997) make provision for the protection of valuable hedgerows (species-rich and historic countryside hedges) and now large quantities of hedges are managed under AES, with significant investment in restoration of stone walls and other traditional boundaries (Posthumus *et al*., 2011). In addition, England's National Park Authorities provide incentive mechanisms for hedgerow restoration and creation (Natural England, 2010).

In the Mediterranean region, the existence of hedgerows dates back to ancient times. They form part of traditional agrosilvopastoral systems where there are important elements of the rural landscape and represent a good example of crop and livestock integration in the landscape (Paoletti *et al*., 2001). Thus, hedgerows contribute to the functionality of these cultural landscapes and provide important ecological and historical value in landscape conservation planning (Schmitz *et al*., 2007). However, nowadays, despite their multifunctionality and multiple benefits, the role of hedgerows is often underestimated in rural Mediterranean regions where in most cases they are remnants of past practices. In Spain, in fact, only a small portion of agricultural landscapes is protected inside the Spanish red Natura 2000, an important regulatory tool to preserve biodiversity in Europe. Therefore, hedgerows are being lost at a dramatic rate because of either agricultural intensification or to the abandonment of traditional activities that had generated and maintained these ancestral cultural landscapes through the application of empirical knowledge (Bernáldez, 1991). The degradation of this rural landscape also represents the decline of habitats associated with the hedgerow network.

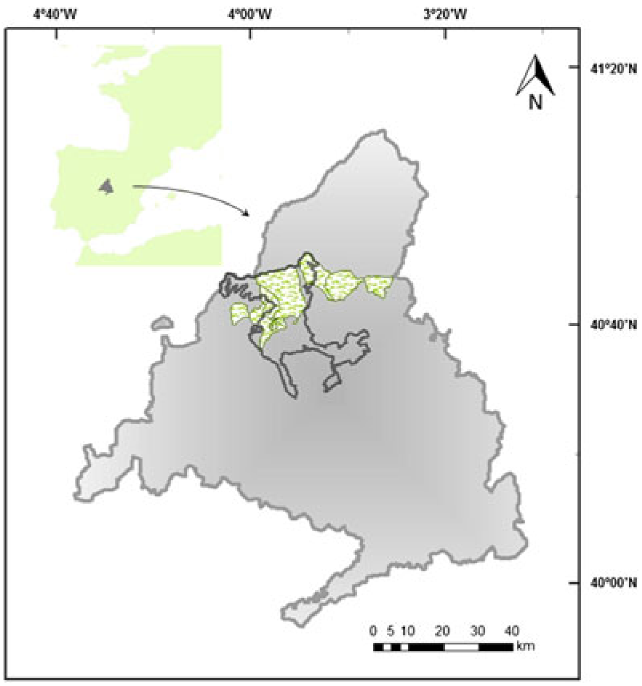

Figure 1. Location of the study area in the Madrid Region (Central Spain). Boundaries of the Regional Park of Upper Manzanares River Basin (dark grey) and municipalities in which hedgerows were sampled are indicated (green). [Colour figure can be viewed at wileyonlinelibrary.com]

We hypothesise that the lack of specific measures to enhance hedgerow conservation favours the disappearance of hedgerow networks, together with species loss and other associated ecosystem services. This study aims to evaluate the role of a Protected Area (PA) in Central Spain on the conservation and management of a traditional Mediterranean hedgerow network. To this end, we empirically examine changes in the composition and richness of woody plant species of a relict hedgerow network, inside and outside the boundaries of a PA.

MATERIAL AND METHODS

Study Area

The study area comprises the southern piedmont of the Guadarrama Mountain Range, to the north of Madrid Region (Central Spain) and ranges from 850 m to 1050 m asl (Figure 1a). The climate is continental Mediterranean, with a dry summer period, with annual rainfall from 700 to 800 mm and an average annual temperature of 10–13 °C. The area is formed by granitoid and gneiss rocks with lithic and dystrict leptosols. The original vegetation is Mediterranean forest and scrub – *Quercus* species (e.g., *Quercus ilex*, *Quercus pyrenaica*, *Quercus faginea*), *Fraxinus angustifolia*, *Cistus ladanifer*, *Lavandula stoechas*, *Cytisus scoparius*, and *Genista cinerea*. This natural vegetation has historically been transformed into a *Quercus* spp. or *F. angustifolia* savannah-like landscape ("dehesa"), used for grazing, interlinked by a conspicuous hedgerow network. Indeed, very old land use systems have created a mosaic of shrubs and trees forming hedgerows between crop fields and pastures grazed by sheep, horses, and cattle, which forms a main part of the landscape. In Central Spain, this system of mixed vegetation is unique and characteristic of mountainous areas and several authors have highlighted their importance (Bernáldez, 1991; Franco-Múgica *et al*., 1998).

The study area comprised areas both within and outside the boundaries of a PA, the Regional Park of Upper Manzanares River Basin (established in 1985). Sampling was undertaken in seven municipalities of which four were totally or partially included inside the PA (>25% of the municipal area), and the remaining three municipalities were located outside the boundaries of the PA and thus had no protection status (Figure 1b). For centuries agrosilvopastoral uses in dehesas have constituted the major traditional economic activity in this territory and the main human influence on the landscape, but in the last three decades the study region has suffered a trend towards abandonment (mainly of livestock farming) and a notable process of encroachment by scrub and trees. Indeed, data of land use dynamics show a loss of around 10% of pasture systems and a gain of Mediterranean forests both inside and outside the PA (Figure 2). It is noteworthy that the tendency towards shrub encroachment has been higher inside the PA, whereas outside it the loss of agriculture systems has been compensated by an increase in dehesa systems (Figure 2).

The origin of the hedgerows in this region is very old (XIII century) and constitutes a valuable natural and cultural heritage. They constitute field boundaries (Müller, 2013) whose origin was dry stone walls built by farmers as a defence (dehesa means *defessa* in Medieval Spanish) against the rights of Mesta transhumance sheep (Sánchez & McCollin, 2015; Schmitz *et al*., 2007). The stone walls are also an integral part of the field margins that surround dehesas and are still useful for cattle management and for rotational grazing from one pasture to another (shifting pastures). Following Sánchez & McCollin (2015), we refer to these structures as ‘hedges’ or ‘hedgerows’ although they comprise a mix of stone wall and woody vegetation growing alongside the wall.

Sampling and Data Collection

In order to select hedgerows in the study area we first identified potential sample sites by locating the presence of hedgerows using aerial imagery. As hedgerows in some sites were very degraded or even missing altogether, we applied a criterion of selection of the hedgerows to be sampled in the field: (i) they had to be at least 30 m long; (ii) no gaps greater than 15 m in woody species could be present (DEFRA (Department for Environment, Food and Rural Affairs), 2007). Sampling was conducted twice, over a period of 10 years (in 2003 and 2013).

A total of 109 hedgerows were located and sampled throughout the study area in 2003. Of these, only 102 were available to be sampled again in 2013. The rest of them had disappeared or altered in a way that they did not fulfil the minimum requirements to be considered in the study. In both 2003 and 2013, each hedgerow was considered as a sampling unit where the linear cover of all species of woody plants was recorded (line–intercept transect method, Mueller-Dombois & Ellenberg, 1974). A mean cover per m^2 of each species in the hedge (sampling unit) was estimated. Nomenclature of species followed Castroviejo (1985–2013).

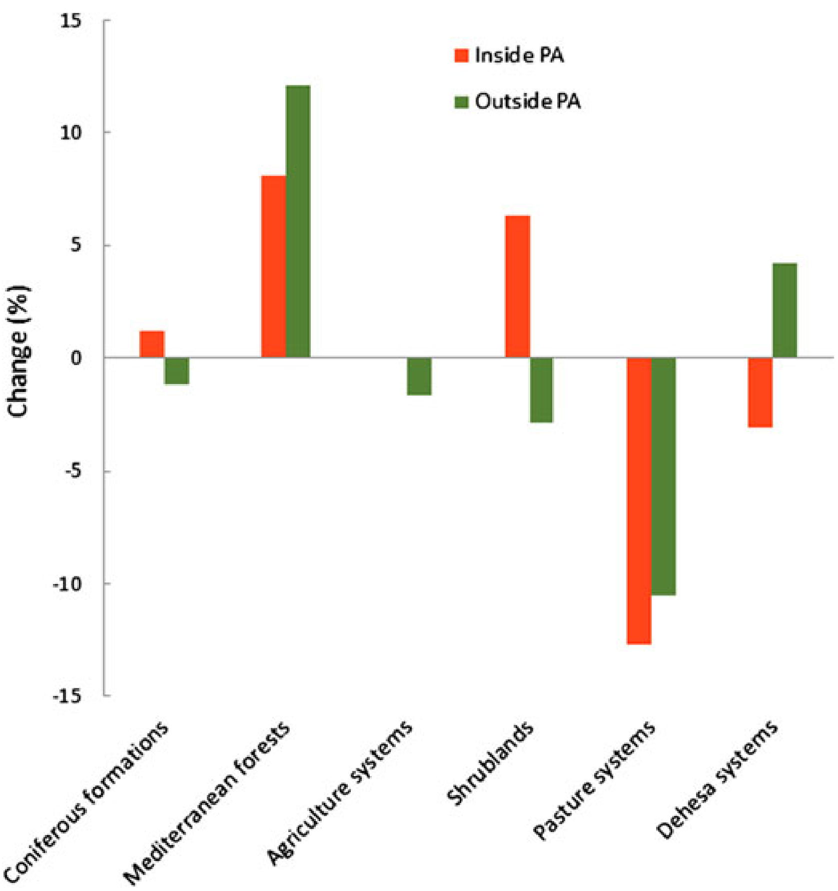

Figure 2. Percentage change of land use inside (red) and outside (green) the boundaries of the Protected Area in the last two decades (1980–2010). [Colour figure can be viewed at wileyonlinelibrary.com]

Data Analysis

A data matrix containing the cover values of the woody species in the hedges sampled in 2003 and 2013 was analysed by a Principal Components Analysis (PCA). Rare species, present in three or fewer hedges in any of the years, were removed to prevent distortion. The multivariate ordination analysis carried out with the resulting matrix (102 hedgerows × 19 species in time t and the same in t_{+1}; **Appendix**) enabled us to order the hedgerows on a plane. The dimensions of this plane depended on the most representative woody plant species, those with the greatest loading in the analysis.

In the two sets of coordinates on the ordination plane, inside and outside the PA, we calculated the intensity of change of the hedgerows over time by means the displacement vectors, $\Delta\overrightarrow{D}_i$, connecting the coordinates of each hedge from time t (C_{t_i}, defined by their position vectors $\overrightarrow{V}_{t_i}$) to the coordinates of each hedge in time t_{+1} (C_{t+1_i}, defined by their position vectors $\overrightarrow{V}_{t+1_i}$). $\Delta\overrightarrow{D_i} = C_{t+1_i} - C_{t_i}$, where $\overrightarrow{V_{t_i}} = x_{t_i} + y_{t_i}$ and $\overrightarrow{V}_{t+1_i} = x_{t+1_i} + y_{t+1_i}$, thus, $\Delta\overrightarrow{D}_i = (x_{t+1} - x_t)_i + (y_{t+1} - y_t)_i$.

The magnitude of displacement vectors, $\Delta\overrightarrow{D}_i$, indicates the intensity of the changes of hedgerows, that equals the modules of the displacement vectors between the coordinates of the hedgerows from time t to time t_{+1}. $\left\|\Delta\overrightarrow{D_i}\right\| = \sqrt{(x_{t+1_i} - x_{t_i})^2 + (y_{t+1_i} - y_{t_i})^2}$

The direction of $\Delta\overrightarrow{D}_i$ in relation to the reference Cartesian system enabled us to determine the tendency of the change of hedgerows towards each end of the ordination axes.

Thus, on the ordination plane, we represented the temporal change using arrows, whose magnitude and direction represent the overall trajectories of change of the hedgerows in terms of floristic composition over time. The statistical significance of the displacement intensity inside and outside the PA boundaries was tested by means of a Student's t-test.

The woody plant species richness of the hedgerows was estimated by considering all the species present, both dominant and rare. The difference in species richness of each hedgerow in 2003 ($n = 109$ hedges) and 2013 ($n = 102$ hedges) was tested using a Student's t-tests.

RESULTS

Examination of the study area using aerial imagery showed that there were approximately 20% more hedges meeting the requirements for sampling outside the PA than inside it. Throughout the study period, seven hedgerows disappeared or were degraded by fragmenting or decreasing their length to less than 30 m. Out of these, five were located outside the PA, and two of them inside it; a total of 6·42% of hedgerows of the study area has disappeared (see **Appendix**).

The PCA plane (Figure 3a) shows the trajectories of change in the floristic composition of hedgerows throughout the period of study. The two main PCA axes together explain 39% of floristic variation. There is a noteworthy difference between the absorption of variance of the first two axes with respect to the third and remaining axes, which were uninformative. According to the loadings of the main variables, Axis 1 represents a gradient of abandonment of pasture systems: from hedgerows linked to grazed pastures and characterised by the presence of *Q. ilex*, highest factor loading at the positive end of the axis, to hedgerows composed mainly of typical shrubs of the underbrush of Mediterranean forest systems, such as *Prunus spinosa*, *Crataegus monogyna*, and *Rosa canina*, with the highest loadings at the negative end of the axis. Axis 2 expresses the hedgerow typology in relation to the phreatic water availability, defined by *F. angustifolia*, with high water requirements, at the positive end of the axis, and *Q. ilex*, with low water requirements, at the negative end.

The calculation of the displacement vectors of hedgerows from 2003 to 2013 on the ordination plane (represented in Figure 3a as arrows) enabled us to identify a similar change both inside and outside PA. The direction of each arrow indicates the change towards the abandonment or towards the conservation-maintenance followed by each hedge (Figure 3a). The main direction of arrows, from right to left of the ordination plane (along Axis 1), is consistent with the tendency to abandonment throughout the period of study, explained by the species with the highest loadings at both ends of Axis 1. This tendency towards abandoned pasture-hedgerow systems is similar in zones with different edaphic water availability (along Axis 2), regardless of their location in relation to PA: 85·71% and 82·61% of hedgerows were abandoned outside and inside PA, respectively. The intensity of change, identified by the modules of the displacement vectors, is also similar regardless of location, so that belonging or not to the PA does not imply significant differences between displacement vectors of hedgerows towards abandonment (to the left end of Axis 1; Student's t-test, $t = 1 \cdot 29$, $p = 0 \cdot 1$) and displacement vectors of hedgerows towards conservation (to the right end; $t = -1 \cdot 10$, $p = 0 \cdot 14$). Figure 3b shows a scheme of the hedgerow network dynamic according to the mean of modules, $|\overline{X}|$, of displacement vectors, $|\overline{X}| = \frac{\sum |x_{t,t+1}|}{n}$, where $x_{t,t+1}$ represent the coordinates of the hedgerows along Axis 1 (x-component) from time t (2003) to $t + 1$ (2013); n is the number of hedgerows changing their coordinates towards abandonment or conservation inside or outside PA.

For the 109 hedges sampled in 2003 (48 inside and 61 outside the PA) and the102 in 2013 (46 and 56 respectively; **Appendix**), it is noteworthy that 66·7% of all species recorded in the study area reduced their presence in the hedgerows or disappeared. Only 33·3% of the woody species of the hedges remained stable or increased their frequency. *Hedera helix*, *Prunus persica*, *Ulmus pumila*, and *Juglans regia*, which were present in 2003, were not found in the whole study area in 2013, although their abundance was already very scarce in the first year studied. The first three were present in 2003 only inside

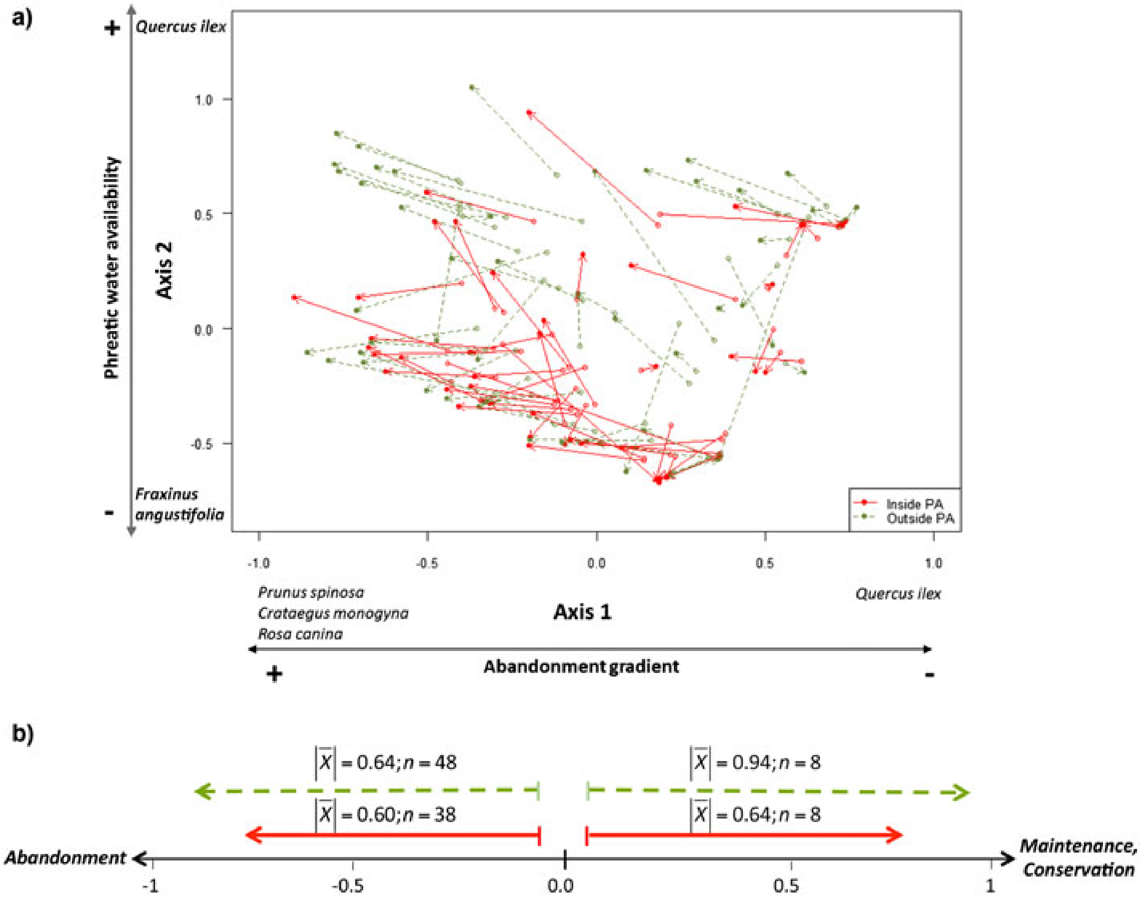

Figure 3. a) PCA plane using 204 observations of hedgerows (102 hedges in 2003 and the same in 2013). Arrows show the direction and magnitude (arrow length) of change in the floristic composition of each hedgerow, inside (continuous line) and outside (dashed line) the Protected Area. Species with the highest scores on each axis are represented. b) Magnitude of displacement vectors (mean of the modules) along Axis 1 towards conservation status (right) or abandonment (left) of hedgerows, both inside (continuous red line) and outside (dashed green line) the Protected Area. |X| indicates the mean of the modules of displacement vectors and n is the number of hedgerows changing their coordinates along the study period towards abandonment or conservation, inside or outside PA. [Colour figure can be viewed at wileyonlinelibrary.com]

the PA, and they disappeared, together with *J. regia*, in 2013. These extinct species account for 13% of woody plant species of hedgerows inside the PA in 2003. Outside PA, 10% of woody species of hedgerows disappeared during the study period, namely *Lonicera etrusca*, *Malus sylvestris*, and *Ruscus aculeatus*. Similarly, 38·7% and 43·3% of the woody species reduced their presence in the hedgerows inside and outside the PA, respectively.

Species richness of hedgerows inside and outside PA decreased from 2003 to 2013 (negative increment of species richness). However, the rate of species loss was 1·55 times higher inside PA than outside it (rate variation = −7·6 inside PA; rate variation = −4·9 outside PA; Table I). Values of Student's *t*-tests (inside-outside PA) were not significant in all cases.

DISCUSSION

The landscape structure of the study area has been the result of ancient land use systems and rural activities that for centuries have been performed in the region contributing to its great social–ecological value, and thus, deserving a protection status. From a historical perspective, this multifunctional landscape contained a heterogeneous mosaic of traditional silvopastoral systems (forestry-grazing) in which hedgerows formed conspicuous networks across the countryside, closing fields traditionally used as pastures.

The landscape change described is the result of a widespread land abandonment, mainly characterised by a decrease in pasturelands and dehesa systems (open oak forests) and an increase in shrubs, trees, and forests as spontaneous reafforestation. This is evident inside PA, where a noteworthy

Table I. Species richness inside and outside the Protected Area in 2003 and 2013

	Sp. richness average		Sp. richness maximum per hedgerow		Sp. richness increment	Sp. richness variation rate
Protected area	2003	2013	2003	2013	2003–2013	2003–2013
Inside	5·23	4·83	12	10	−0·40	−7·6
Outside	4·46	4·26	9	9	−0·22	−4·9

abandonment occurs (Figure 2). The process shows the management weakness of this PA, among whose objectives is precisely the conservation of traditional landscape (Schmitz *et al*., 2012). The abandonment of pasture systems occurred in recent decades has resulted in the loss of a long-standing cultural landscape (Millington *et al*., 2007; Rocchini *et al*., 2006; Verdú *et al*., 2000), with a noticeable impact on hedgerow networks and therefore, upon their diversity of woody species, the maintenance of connectivity between habitats, landscape resilience, and other ecosystem services provided by hedgerows. In our study, seven of the hedges sampled in the first year disappeared or were degraded after a decade, which represents a loss of 6·42% of existing hedges in the study area. This seems to be a very high rate of loss. In the UK, over the last two decades, successive surveys have noted a 6·6% decline in the number of hedgerows (Carey *et al*., 2008 Haines-Young *et al*., 2000). This is a disappearance rate rather smaller (3·3% per decade) than of the one observed in the study area.

Our results clearly show a notable tendency towards degradation of the hedgerow network, linked to the abandonment of adjacent pastures and the subsequent process of shrub encroachment (Figure 3a; Axis 1). Most hedgerows (82·6% and 85·7%, inside and outside PA, respectively) are linked to the abandonment process, showing a noteworthy encroachment by shrubs such as *P. spinosa*, *C. monogyna*, and *R. canina*. These species, with spinose structures, have an intermediate palatability and are grazed under very high livestock pressure (Baraza *et al*., 2006; Plachter & Hampicke, 2010). This tendency is coherent with the process of abandonment of rural cultural landscapes in the Mediterranean basin and is a common trend in the studied region (Bernáldez, 1991; Lasanta *et al*., 2006; Mouillot *et al*., 2005; Petanidou *et al*., 2008; Plieninger, 2006; Schmitz *et al*., 2012). The rest of hedges studied (17·4% and 14·3%, inside and outside PA respectively) are related to a minority of conservative management practices. These traditionally managed hedges are characterised by the presence of trees of the original Mediterranean forest, *F. angustifolia* and *Q. ilex*, which are dominant in different environmental situations related to the phreatic water level. The leaves and young branches of these trees have traditionally been used as fodder (Schmitz *et al*., 2007). It should be noted that the relative importance of this conservative management practice is greater outside than inside PA, as shown by the mean of modules of x-component (along Axis 1) of displacement vectors (0·94 and 0·64, outside and inside PA, respectively; Figure 3b).

The hedgerow abandonment process is also related to the decline and loss of species. The hedgerow network studied contains species-rich hedges, defined as those composed on average by four or more woody species, along the 30 m length sampled (DEFRA (Department for Environment, Food and Rural Affairs), 2007). However, the species richness of the network decreased in a decade both inside PA (decline: 38·71%; disappearance: 10%) and outside PA (decline: 43·33%; disappearance: 12·9%). In this context, the most noteworthy fact is how the rate of species loss is higher inside PA (−7·6) than outside PA (−4·9; Table I).

The relict hedgerow network studied presents a noteworthy degradation process which affects both the decrease in the number of hedges and the decline and local extinction of some woody species that compose them both inside and outside the PA (see **Appendix**). Some of these species are recorded in advisory lists for species conservation. Thus, English walnut (*Juglans regia*), already not found inside the PA in 2013, has a status of “Near threatened” in the IUCN Red List of Threatened Species (IUCN (International Union for Conservation of Nature), 2014), which means “It is likely to qualify for a threatened category in the near future”. Similarly, the Wild apple tree (*M. sylvestris*), decreasing inside PA and missing outside PA, is considered of “Special Interest” by the Regional Catalogue of Threatened Species of the Community of Madrid, which refers to “Species that deserve special attention because of their scientific, ecological, cultural value or uniqueness” (Madrid Government, 1992). Taking into account these statements of the Government itself, this could reveal some inadequacy of the monitoring or management of the PA (“common weaknesses in the management of PAs”; Parrish *et al*., 2003).

In the study area, ecological changes are currently connected with ongoing socioeconomic shifts. These can determine trends that derive from the strong influence of socioeconomy on land use dynamics. As with many other Mediterranean regions, these changes have undergone a sharp decline in farming, with consequent rural abandonment (Schmitz *et al*., 2012). Land abandonment is a general phenomenon with different environmental consequences in agriculture (van Hall *et al*., 2016) and soil–vegetation relationships, particularly in semiarid regions (Alonso-Sarría *et al*., 2016; Cammeraat *et al*., 2010; Cerdà, 1997b). Thus, an important factor that affects hedgerow habitats is linked to the loss of traditional countryside skills and the resulting neglect of hedges. This leads to relict and dysfunctional hedgerows that become lines of trees and tall bushes, usually with rapidly developing gaps, which are more likely to be removed, and to the loss of hedgerow trees through natural decay, disease, storm damage, and physical removal. Thus, in many cases, the result of the abandonment process is the removal or alteration of hedges. These processes are related to the decline of livestock farming, which has a significant impact upon biodiversity (Boatman *et al*., 2007; Petit *et al*., 2003). Fragmentation and habitat loss are the greatest threats to biodiversity and ecosystem services and their effects can be highly detrimental to the persistence of species (Fahrig, 2003). The maintenance of hedgerow length is a good descriptor of the rural landscape structure and habitat conservation (Gillings & Fuller, 1998; Scozzafava & de Sanctis, 2006). The reduction of hedgerow size results in the loss of food and shelter, and it has been involved in the decline of wildlife (Bright & MacPherson, 2002), because a reduction in landscape connectivity decreases the probability of individuals successfully moving between habitat patches (Hanski *et al*., 2000).

Figure 4 summarises the change in hedgerow landscape found in the study area. The Regional Park of Upper Manzanares River Basin contains an old and unique hedgerow network. Nevertheless, the ancient and species-rich hedgerows of the study area, which once were singular linear landscape elements, are now remnants of old land uses, even though they are within a PA (Schmitz *et al*., 2007). Furthermore, inappropriate hedgerow management led to a drastic loss of multifunctional hedgerows through abandonment and removal. In this respect, the study of the network dynamic in the PA and its surrounding lands indicates that the land protection scheme is not preventing the loss of hedges, subjected to a noteworthy process of shrub encroachment, fragmentation or removal. A tendency towards the abandonment or maintenance of hedgerows has been equivalent inside and outside the boundaries of the PA, revealing a lack of effectiveness of the Regional Park to fulfil its conservation objectives. The inefficiency in PA management and assessment is illustrated at least by the fact that the rate of species loss is higher inside than outside the PA, and because some of the species that disappeared from hedgerows are recorded in the reference lists for the conservation of species with a high protection status. Several studies underscore the loss of habitat representativeness and conservation capacity in protected natural areas. In a particular region, more habitats are often found outside a PA system than inside (Schmitz *et al*., 2012, among others). In fact, the Protected Area Management Planning aims at "improving, recovering and implementing traditional productive activities, agricultural, cattle raising and forest management, as a means of preserving and actively protecting physical environment", and its regulatory framework specifies which activities are allowed and how. However, in the same document, there is no particular mention to hedgerows (PRCAM, 1997).

Regulation for protection of hedgerows should be based on sound science and a precise definition of their role and contribution to social objectives as other countries have done (Baudry *et al*., 2000). Given their socio-ecological importance and risk status, there should be a particular legislation in Spanish hedgerows, as there is in other European countries. At least, PAs of cultural landscapes should specifically address hedgerow management, which would require information and decisions on location, management, and pattern. Nevertheless, management plans of Spanish PAs barely mention them.

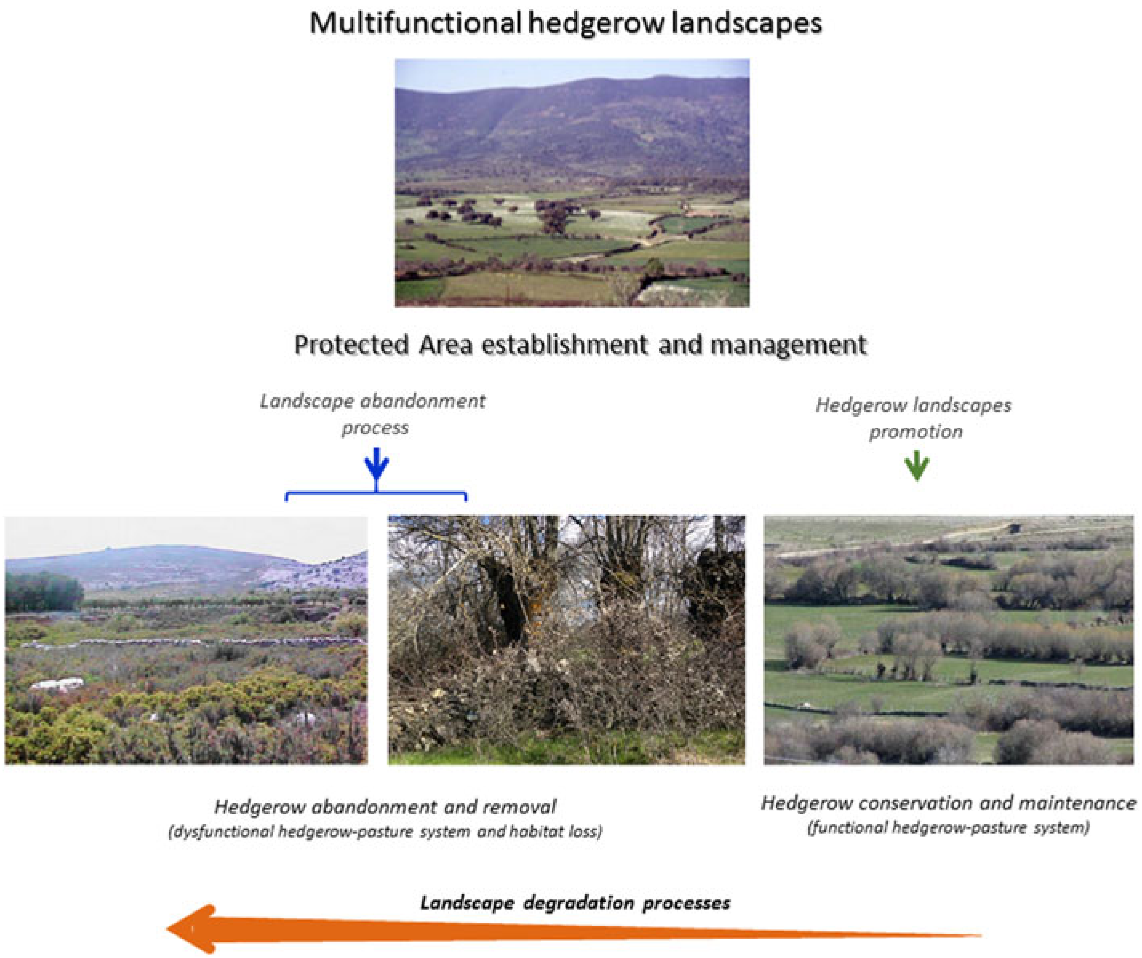

Figure 4. Schematic overview of the hedgerow network dynamic in the Protected Area and its surrounding lands. Hedgerow conservation and maintenance are illustrated by means of a zone with a high-phreatic water availability (hedges with *F. angustifolia*). Nevertheless, the gradient of abandonment occurs both in these environments and in drier areas (*Q. ilex* as dominant species; Axis 2, Figure 3). [Colour figure can be viewed at wileyonlinelibrary.com]

CONCLUSION

Conservation of cultural landscapes, with hedgerow networks and associated ecosystem services, is linked to the maintenance of traditional management activities. Excessive regulation inside PAs typically inhibits rural activities and therefore promotes undesirable consequences such as rural abandonment and hedgerow disappearance. In this paper, a process of abandonment of pasture systems, including degradation and loss of associated hedgerows, was detected inside and outside the PA studied. This process is also related to the loss of woody species of conservation interest. We strongly recommend that financial incentives should be put in place to encourage traditional rural activities inside those PAs which aim to protect cultural landscapes. We also propose a conservation status for hedgerows in the legislation of Spanish PAs. These proposals may be useful to improve the design and management of these areas so that they can effectively serve to preserve cultural biodiversity.

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APPENDIX

a) Number of hedgerows sampled in 2003 and 2013 inside and outside PA. b) Woody plant species sampled in the hedgerow network during the study period, both inside and outside PA. An asterisk indicates the uncommon species, which were not considered in the PCA analysis because of their rarity (presence in the hedgerows in any year < 3). Species that disappeared from the hedges (17·95% of all species recorded in the study area) or whose presence decreased over the study period (48·72% of them) are indicated in bold.

a) Hedgerows	Protected area				
	Inside		Outside		Total
2003	48		61		109
2013	46		56		102
b) Species	Inside		Outside		
	2003	2013	2003	2013	
*Acer monspessulanum**	1	2	1	1	
Bryonia dioica	2	1	9	8	
Crataegus monogyna	21	19	22	25	
Cytisus scoparius	3	2	3	2	
Daphne gnidium	3	2	2	2	
Euonymus europaeus	9	12	11	11	
Ficus carica*	0	0	3	2	
Fraxinus angustifolia	38	37	30	30	
Hedera helix*	1	0	0	0	
Jasminum fruticans	0	0	8	7	
Juglans regia*	3	0	2	1	
Juniperus oxycedrus	2	2	5	5	
*Ligustrum vulgare**	2	2	1	1	
Lonicera etrusca	5	4	6	0	
*Lonicera periclymenum subsp. lusitanica**	0	0	1	7	
Malus sylvestris*	3	2	1	0	
Olea europaea*	0	0	2	1	
*Osyris alba**	0	0	1	1	
*Populus alba**	2	2	0	0	
Populus nigra*	2	1	0	0	
*Prunus domestica**	0	2	1	1	
Prunus dulcis*	0	0	2	1	
Prunus spinosa	23	21	25	28	
Prunus persica*	1	0	0	0	
*Quercus faginea**	1	1	1	2	
Quercus ilex	14	16	18	17	
Quercus pirenaica	15	13	2	1	
Rhamnus cathartica	7	9	9	11	
*Robinia pseudacacia**	1	1	0	0	
Rosa canina	26	21	34	33	
Rubus ulmifolius	38	41	44	41	
Ruscus aculeatus*	0	0	1	0	
Salix atrocinerea	4	4	0	0	
*Salix purpurea**	2	2	0	0	
Salix salvifolia	6	6	1	1	
*Santolina rosmarinifolia**	1	1	0	0	
Tamus communis	2	2	3	2	
Ulmus minor	6	5	20	19	
Ulmus pumila*	1	0	0	0	

ARTÍCULO 07

Título: Losing a heritage hedgerow landscape. Biocultural diversity conservation in a changing social-ecological Mediterranean system

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Resumen:

Los paisajes rurales tradicionales albergan un patrimonio biocultural adquirido por las sociedades rurales y desarrollado en una adaptación secular con la naturaleza. Los setos juegan un papel clave en la preservación de la diversidad biocultural y en el suministro de los servicios de los ecosistemas asociados. A pesar de sus beneficios, en algunas regiones europeas la gestión de inadecuada de las redes de setos ha tenido como consecuencia su drástica degradación, con efectos significativos sobre la diversidad natural y biocultural, la conectividad del paisaje y el flujo sostenible de los servicios ecosistémicos. En el centro de España, un antiguo paisaje de setos constituye un valioso patrimonio natural y cultural reconocido por medio del establecimiento de diferentes figuras de protección. En este artículo se cuantifica la principal tendencia de cambio de este paisaje a lo largo del tiempo, detectando un proceso de desacoplamiento socio-ecológico rural, tanto dentro como fuera de los Espacios Naturales Protegidos establecidos en el área de estudiio . La red de setos se ha degradado y desestructurado progresivamente junto con el declive y la extinción local de especies leñosas, todas ellas de uso tradicional y algunas registradas en listas rojas para la conservación de especies. Esto revela deficiencias en el diseño y los planes de manejo de las áreas protegidas que deberían ser efectivas en la conservación del patrimonio de los paisajes culturales y de su valiosa diversidad biocultural y de la provisión de servicios de los ecosistemas. Es necesario elaborar normas para la protección de los paisajes de setos en la legislación española, basadas en las relaciones socio-ecológicas.

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Losing a heritage hedgerow landscape. Biocultural diversity conservation in a changing social-ecological Mediterranean system

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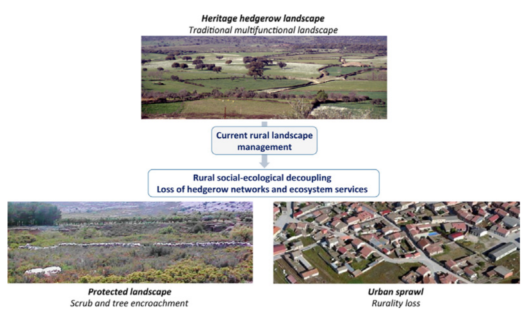
HIGHLIGHTS

- We studied an ancient hedgerow network of medieval origin in Central Spain.
- There is a process of rural social-ecological decoupling of the hedgerow landscape.
- The hedgerow network has been degraded both inside and outside protected areas.
- Multiple use hedge species decline affecting the provision of ecosystem services.
- New regulations for the protection of hedgerow landscapes are needed.

GRAPHICAL ABSTRACT



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ABSTRACT

Traditional rural landscapes host a biocultural heritage acquired by rural societies, developed in a secular adaptation with nature. Hedgerows play a key role in preserving biocultural diversity and associated ecosystem services. Despite their benefits, in some European regions inappropriate hedge management has led to a drastic degradation of hedgerows, with significant effects on natural and biocultural diversity, landscape connectivity and sustainable flow of ecosystem services. In Central Spain, an ancient hedgerow landscape constitutes a valuable natural and cultural heritage recognized by the establishment of different protection categories. We quantify the main tendency of change of this landscape over time, detecting a process of rural social-ecological decoupling both inside and outside protected areas. The hedgerow network has progressively been degraded and destructured together with the decline and local extinction of woody species, all of them of traditional use and some recorded in red lists for species conservation. This reveals weaknesses in the design and management plans of protected areas that should be effective in conserving the heritage of cultural landscapes and their valuable biocultural diversity and provision of ecosystem services. There is a need to elaborate regulations for the protection of hedgerow landscapes in the Spanish legislation, based on social-ecological relationships.

1. Introduction

Hedgerows are key features in many traditional agrosilvopastoral systems. Usually they are man-made and have been planted by rural societies from the Neolithic period with the main aim of closing fields (Morgan Evans, 1994). Traditionally, hedgerows have as their prime agricultural roles to serve as field boundaries, windbreaks and fences for livestock, providing them with food and shelter (Baudry et al., 2000; Bird et al., 2002; Harvey et al., 2005). It is undeniable that hedges exist in the landscape because they have real agricultural functions and that the development of the hedgerow landscape is linked to the evolution of agricultural and livestock activities (Marshall and Moonen, 2002).

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These networks of woody vegetation across landscape also perform important ecological functions, promoting biodiversity and providing provisioning, regulating and cultural ecosystem services (Millennium Ecosystem Assessment, 2005; Dainese et al., 2016). They improve crop productivity, reduce pest incidence (Marshall and Moonen, 2002; Morandin et al., 2014), maintain landscape connectivity (Baguette et al., 2000; Hanski et al., 2000; Busck, 2003; Davies and Pullin, 2007; Wehling and Diekmann, 2009; Staley et al., 2012), protect soils and reduce erosion (Keesstra et al., 2016) and processes associated with this regulation ecosystem service, such as the movement of sediments, fertilizers and pesticide from agricultural lands (Logsdon and Chaubey, 2013; Novara et al., 2013). Likewise, it is increasingly documented that hedgerow networks provide valuable breeding habitat, refuge and food for wildlife and can help to sustain beneficial species (Dover and Sparks, 2000; Olson and Wäckers, 2007; Boughey et al., 2011; Buse, 2012; Miñarro and Prida, 2013; Morandin and Kremen, 2013; Cross et al., 2015, among others). Specifically, hedgerows can serve to develop a network of ecological corridors that can facilitate the movement of beneficial organisms, such as pollinators, in the landscape matrix (Schmucki and De Blois, 2009; Morandin and Kremen, 2013; Dainese et al., 2016). In addition, hedgerows have significant historical and cultural values, hosting many useful species with symbolic, ritual and ceremonial uses (Burel and Baudry, 1995; Baudry et al., 2000; Macdonald and Johnson, 2000; Busck, 2003; Schmitz et al., 2007; Alignier and Baudry, 2015).

Given the ecological multifunctionality of hedgerows and their importance for sustainable agriculture and conservation of rural biodiversity (Deckers et al., 2005; Schmitz et al., 2017), the EU Biodiversity Strategy has designated hedgerows as a priority habitat for conservation (JNCC-DEFRA, 2012) and some European countries have developed programs for the conservation and restoration of hedgerow networks in institutionalized frameworks, encouraging farmers to plant hedges through subsidy schemes with public funding (Busck, 2003; Kleijn and Sutherland, 2003; Croxton et al., 2004; Boughey et al., 2011; Fuentes-Montemayor et al., 2011). Thus, hedgerow management, conservation and restoration activities can be considered as dependent on social-ecological systems with multiple interactions and feedbacks between landscape characteristics, local actors, socioeconomic conditions, land planning and public support (Busck, 2003; De Aranzabal et al., 2008; Rescia et al., 2010; Palomo et al., 2011; Schmitz et al., 2018). Since hedgerows play a key role in the maintenance of biodiversity and functionality of landscapes, they can be used as indicators of the state of conservation of rural landscapes providing an ecological, social and historical valuable basis for conservation and land-use planning (Burel and Baudry, 1995; Schmitz et al., 2007). However, despite their social-ecological benefits and conservation efforts, in some European regions inappropriate hedge management has led to a drastic loss of hedgerow networks. Over the last decades, both rural abandonment and agricultural intensification processes, the main land use change trajectories (Schmitz et al., 2003; Antrop, 2006; Antrop and Van Eetvelde, 2008; De Aranzabal et al., 2008; Nainggolan et al., 2012), have resulted in the widespread loss, removal or alteration of long-standing hedgerows in many regions with significant effects on natural and biocultural diversity (Le Cœur et al., 2002; Deckers et al., 2005; Schmitz et al., 2007, 2018; Sánchez et al., 2010; Boughey et al., 2011). The hedgerow degradation process has serious implications for species conservation, maintenance, connectivity and resilience of cultural landscape and the preservation of a sustainable flow of ecosystem goods and services to society (Dover and Sparks, 2000; Bengtsson et al., 2003; Lindborg and Eriksson, 2004; Davies and Pullin, 2007; Olson and Wäckers, 2007; Essl et al., 2015).

Faced with the increase in habitat degradation, loss of biodiversity and alteration of ecological processes, protected areas (PAs) represent the cornerstone of conservation efforts (DeFries et al., 2005; Nelson and Chomitz, 2011). PAs, designed to safeguard remaining habitats and species, are central to conservation strategies and their effectiveness can range from areas with inclusive and adaptive programs for sustainable management to areas with no active management, known as "paper parks" (Timko and Innes, 2009; Nagendra et al., 2013). Hedgerow network landscapes need to be actively managed in order to be maintained, and current socioeconomic changes, as well as a misunderstood idea of preservation of nature, do not favour their conservation. In recent years the effectiveness of some measures to conserve nature and biodiversity is being questioned, since land conservation policies have frequently been defensive and management plans often neglect or even restrict traditional rural activities and forget the local population, which have contributed to the high conservation values recognized in cultural landscapes (Le Cœur et al., 2002; Schmitz et al., 2012). In the Mediterranean region, traditional grazing activity has favoured the diversity of habitats and species (Montalvo et al., 1993), but nature protection policies focused on naturalness and wilderness have led to the restriction and elimination of grazing in many PAs (Verdú et al., 2000). These nature conservation efforts have resulted in the decline of functional species composition and plant diversity of pasture systems (Peco et al., 2006), loss of natural and biocultural diversity and, ultimately, in the abandonment of the rural landscape and the reduction or disappearance of traditional knowledge (Verdú et al., 2000; Millennium Ecosystem Assessment, 2005; Plieninger, 2006; Petanidou et al., 2008; Schmitz et al., 2012). Additionally, too often management plans of PAs are dependent on administrative boundaries and political legislation, and not on social-ecological relationships, biophysical processes and ecosystem services fluxes. This reduces their effectiveness in protecting landscapes based on social-ecological interactions, such as hedgerow landscapes (DeFries et al., 2007).

This study was undertaken in order to analyse the temporal evolution and conservation status of a relict hedgerow landscape of medieval origin in Central Spain, partially included within the boundaries of different categories of PAs. The aims were: i) to evaluate the social-ecological changes of the region, explicitly considering hedgerows as integral components of the local social-ecological systems; ii) to assess the gap between the management targets of PAs and the effective hedgerow network conservation. To this end we empirically examine the typology and dynamics of the social-ecological interactions and the main indicators of change of the hedgerow landscape studied, inside and outside the boundaries of PAs.

2. Methods

2.1. Study area

The study area is located in the piedmont of the southern slope of the Guadarrama Mountain Range, in the Madrid Region (Central Spain; Fig. 1a). The climate is continental Mediterranean and the substrate consists of granitoid and gneiss rocks with lithic and dystrict leptosols. The natural vegetation is Mediterranean forest comprising different species of trees and scrubs (*Quercus ilex*, *Q. pyrenaica*, *Q. faginea*, *Fraxinus angustifolia*, *Cistus ladanifer*, *Lavandula stoechas*, *Cytisus scoparius* and *Genista cinerea*, among others). Throughout centuries, the area has become a human-shaped landscape where original forests have been transformed into *dehesas* (open savannah-like woodlands used as pastures) of *Quercus* spp. or *Fraxinus angustifolia* interconnected by hedgerow networks. This results in a multifunctional silvopastoral system that has constituted the main traditional economic activity in this territory (Schmitz et al., 2012). In this area, the hedgerow network landscape is very old (13th century) and constitutes a valuable natural and cultural heritage (Fig. 1b). In its origin, dry stone walls enclosing pastures were built by farmers as a defence against the transhumant herding of the Mesta, mainly sheep. Hedges comprise a mix of stone walls and woody vegetation growing alongside the wall and their original structure and spatial configuration of the fields and drove roads were

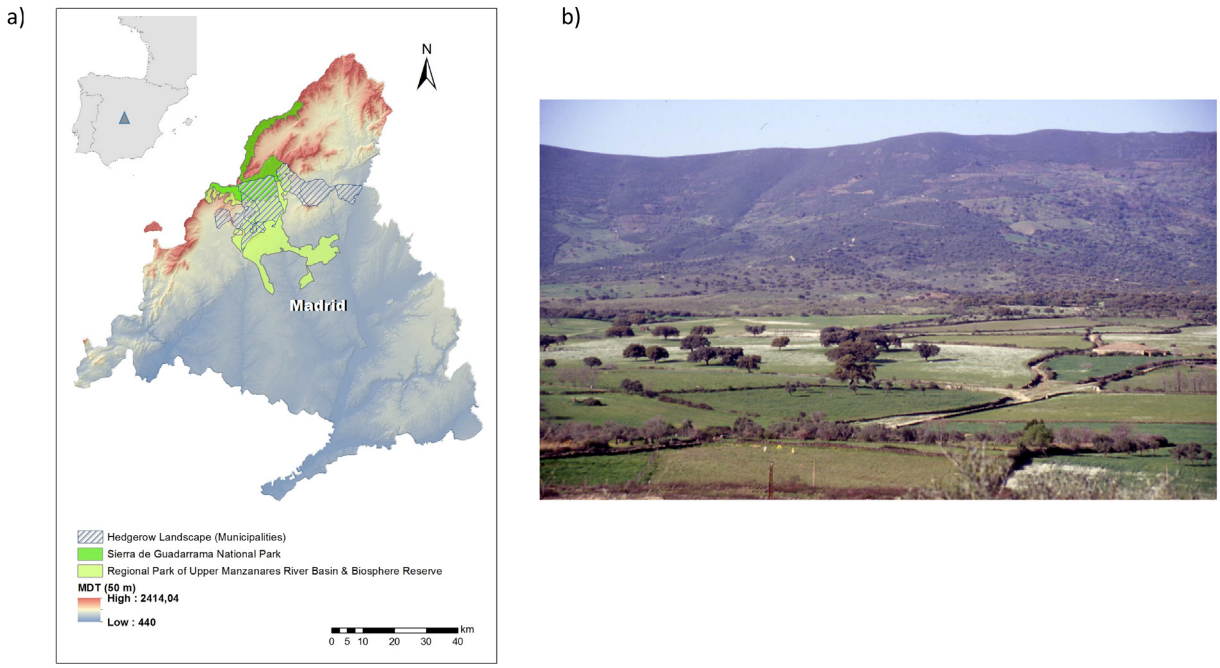

Fig. 1. a) Location of the study area in the region of Madrid (Central Spain). Boundaries of the protected areas and municipalities where the hedgerow network remains are indicated; b) current appearance of the relict hedgerow landscape, still functional in some places.

specifically adapted to sheep (Schmitz et al., 2007; Sánchez and McCollin, 2015).

This area is, therefore, a social-ecological system with high natural and cultural values recognized by the Madrid Regional Government, which in 1985 protected part of the study zone with the status of Regional Park ("Regional Park of Upper Manzanares River Basin"; BOCM, 1985), a protection status similar to the IUCN VI protected area management category (IUCN, 1994). In 1992, the whole area of the Regional Park was designed as a UNESCO Biosphere Reserve. Since 2013 several thousand hectares of this nature reserve overlap with the Sierra de Guadarrama National Park (Fig. 1), declared of Spain's general interest (BOE, 2013).

Nowadays, the hedgerow network studied is in the territory belonging to seven municipalities of which four are totally or partially included inside PAs (>25% of the municipal area). The remaining three municipalities are located outside the boundaries of the PAs, in the peripheral belt known as "socioeconomic influence area", SIA, (BOE, 1989), and thus have no protection status (Fig. 1a). The set of municipalities in which the relict hedgerow network persists covers an area of ca. 35,000 ha. In recent decades, population growth (the population has grown at an average rate of 50% in the period 1999–2010) and urban expansion have been remarkable in the study area.

2.2. Social-ecological descriptors of the hedgerow landscape context. Data collection and sampling

To analyse the dynamics of change of the hedgerow landscape studied we considered a set of social-ecological variables that characterizes both the rural landscape and the local population structure and which are related to the typology and management of the territory (De Aranzabal et al., 2008). The spatial reference units were the municipalities that currently maintain the relict hedgerow network, both within the limits of the PA and in the peripheral SIA. Municipalities are the administrative divisions of local landscape management and governance decisions -i.e. where the policy decisions are taken- and the socioeconomic information is registered at this scale (Schmitz et al., 2003; Verburg et al., 2010; Salvati and Serra, 2016).

We recorded temporal quantitative information referring to hedgerow landscape descriptors and socioeconomic features of the local population: a) six land use-land cover (LULC) types, obtained from preexisting land use maps (reclassified from SIGA, 1999–2010; Table 1a). Land uses selected are the most significant of the study area at present, representing the greatest human influence in the configuration of the current cultural landscape. Many of them are considered as traditional land use systems of the rural landscape. Thus, land uses such as

Table 1a
Land use and land cover (LULC) descriptors recorded in each municipality of the study area. The unit of measure was percentage area respect to municipal area.

Land uses	Description
Mediterranean woodlands	Woodlands with forests of Holm oak (*Quercus ilex*), Pyrenee oak (*Q. pyrenaica*), juniper (*Juniperus oxycedrus*) and different types of scrubs
Coniferous formations	Plantations and mature forests of Scots pine (*Pinus sylvestris*) and black pine (*P. nigra*) in hillside slopes and pinaster pine (*P. pinaster*) in the valley bottoms
Pasture systems	Pasturelands and open formations with a mixture of pastures and isolated Trees (dehesas)
Agricultural systems	Traditional mixed agricultural uses with permanent crops, shifting cultivation systems and cereal crops integrated in open wooded areas, mainly dehesas and Holm oak forests
Pasture systems with scrubs	Pastures and dehesas dominated by high cover of scrubs of different types (shrub encroachment)
Urban areas	Traditional villages and towns; urbanized areas linked to urban expansion and urban sprawl

Table 1b
Landscape metrics used to calculate landscape patterns in each municipality of the study area. A brief description of each metric and its method of calculation are indicated.

Landscape metrics	Formula	Range	Description
Patch richness	$PR = m$ m = number of patch types present in the landscape,	$PR \geq 1$, without limit	Number of different patch types present within the landscape boundary.
Splitting index	$SPLIT = \frac{A^2}{\sum_{j=1}^{n} a_{ij}^2}$ aij = area (m^2) of patch ij. A = total landscape area (m^2)	$1 \leq SPLIT \leq$ number of cells in the landscape squared	Increases as the landscape is increasingly subdivided into smaller patches and achieves its maximum value when the landscape is maximally subdivided; that is, when every cell is a separate patch.
Edge contrast index	$ECON = \frac{\sum_{k=1}^{m} (p_{ijk} \times d_{ik})}{P_{ij}} \times (100)$ P_{ijk} = length (m) of edge of patch ij adjacent to patch type (k) d_{ik} = dissimilarity (edge contrast weight) between patch types i and k. P_{ij} = length (m) of perimeter of patch ij.	$0 \leq ECON \leq 100$	This index is a relative measure of the amount of contrast along the patch perimeter.
Euclidean nearest neighbour distance	$ENN = h_{ij}$ h_{ij} = distance (m) from patch ij to nearest neighbouring patch of the same type (class), based on patch edge-to-edge distance, computed from cell center to cell center.		Distance (m) to the nearest neighbouring patch of the same type, based on shortest edge-to-edge distance. Has been used extensively to quantify patch isolation
Largest patch index	$LPI = \frac{Max\ (a)}{A} \times (100)$ a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2)	$0 < LPI < 100$	Percentage of the total landscape comprising the largest patch
Hedgerow density	$HD = \frac{Hl}{A}$ Hl = total hedge length (m) A = total landscape area (km^2)		Total hedge length in relation to the total landscape area

agricultural lands, pastures, dehesas and woodlands have constituted the main economic activity in this territory for centuries (Schmitz et al., 2012). Over the last few decades, shrub encroachment, mainly linked to the abandonment of pasture systems, and urban expansion are two relevant landscape change tendencies, which have caused important modifications in the study region (Arnaiz-Schmitz et al., 2018). LULC were quantified as percentage of the municipal area occupied; b) six landscape metrics, five of them (patch richness, largest patch index, euclidean nearest neighbour distance, edge contrast index and splitting index) were calculated from Corine land-cover maps for the years 2000 and 2012 (Table 1b, see below the calculation procedure). The sixth landscape metric considered (density of the hedgerow network) was measured directly in the field (recorded during the hedge sampling period 2003–2013; Table 1b); c) six socioeconomic descriptors (Table 1c) related to local population structure (population density, population aging), population dynamics (immigration, emigration), economic living conditions (income per capita) and contribution of the primary sector to the local economy (agricultural sector GDP). Socioeconomic data were obtained from public census (IECM, 2000–2010); d) structural and biotic characteristics of the hedgerow network (number and length of hedgerows and hedge woody species, respectively; Table 1d), with data collected from field sampling (2003 and 2013).

LULC, landscape metrics and socioeconomic variables were recorded or calculated in two periods prior to the years in which the hedges were sampled (2003 and 2013, see below the hedgerow sampling description). These periods were selected considering available databases and the importance of considering time-lagged responses of biodiversity to environmental changes when managing landscape (Petit and Burel, 1998; Chamberlain et al., 2000; Ernoult and Alard, 2011; Ramalho and Hobbs, 2012; Alignier and Aviron, 2017).

2.2.1. Calculating landscape structure metrics

To analyse the dynamics of the hedgerow landscape structure we selected six spatially explicit and non-redundant landscape metrics (see a brief description of each metric in Table 1b), easy to interpret and with high capacity to describe landscape patterns (Arnaiz-Schmitz et al., 2018). This metrics were calculated in each of the seven municipalities, four of them inside the boundaries of PAs. For this, we used rasterized CORINE Land Cover Maps (years 2000 and 2012), reclassifying land cover classes into the six LULC types previously selected (Table 1a). We generated a raster map of each of these metrics, using a round

Table 1c
Socioeconomic variables recorded in each municipality of the study area. A brief description and units of measurement are indicated.

Variables	Units	Description
Agricultural sector GDP	Percentage	Gross domestic product from the agricultural sector
Income per capita	Euros	Disposable income per capita
Population density	Inhabitants/km^2	Average number of inhabitants per km^2
Population aging	Percentage	Population of 65 years and over in relation to total population
Emigration	Percentage	Number of people that have changed their home outside the municipality in relation to total population
Immigration	Percentage	Number of people from another place who establish their home in the municipality in relation to total population

Table 1d
Descriptors of the structural and biotic features of the hedgerow network. A brief description and units of measurement are indicated.

Hedgerow descriptors	Units	Description
Amount of hedgerows	Number	Total number of hedges within the limits of each municipality
Length of the hedgerow network	Linear meters	Length of the hedgerow network within the limits of each municipality
Woody species richness	Number	Number of woody species registered in the hedgerow network within the limits of each municipality

moving window with a radius of 100 m, and then extracted a mean value for each metric in each of the municipalities included in the study area. We used Fragstats (McGarigal et al., 2012) for the calculation of the landscape metrics.

2.2.2. Hedgerow sampling

The hedgerow network sampled was included in the administrative limits of the municipalities studied, inside and outside the limits of PAs. The selection and sampling strategy applied for a hedge to be considered as such involved two main criteria: hedgerows should have a length of at least 30 m and no gaps >15 m in which woody species could be present (DEFRA, 2007). Following these criteria, in 2003 the hedgerow network had 109 valid hedges for their sampling and monitoring. The new sampling carried out in 2013 allowed us to verify that seven of them had disappeared or were seriously damaged, so they had to be discarded because they did not meet the minimum requirements to be sampled and monitored. In both periods, the length (meters) of each hedge sampled was measured.

A total of 39 species were recorded in the time span studied (Appendix A). All of them were associated with the traditional use of the local population, providing different ecosystem services. Furthermore, we assigned to each species its traditional use, ecosystem service provided, and identified its conservation status in the hedgerow network and its category of protection according to red lists (Appendix A). Nomenclature of species followed Castroviejo (1985–2013).

2.3. Data analyses

2.3.1. Modelling social-ecological interactions

We used a procedure based on Schmitz et al. (2018) to quantify the links between the landscape characteristics (LULC and landscape metrics) and the socioeconomy of the municipalities studied. Thus, with the landscape descriptors and socioeconomic data collected, we elaborated two matrices of quantitative data describing the municipalities in the time span studied from a social-ecological perspective. The dimensions of the matrices were 14 × 12 and 14 × 6, respectively.

We applied a Canonical Correlation Analysis (CCA) that allowed us examining the relationship between the two sets of social-ecological variables (Sherry and Henson, 2015). Previously, we had checked the data to account for analytical requirements. CCA generates axes producing the greatest possible correlation between the variables. This multivariate ordination analysis enabled us to quantify the change in time of municipalities and to detect indicators of socioeconomy–landscape relationships and their social-ecological coupling (according to Arnaiz-Schmitz et al., 2018; Schmitz et al., 2018).

We calculated the intensity of change over time by means of the modules of displacement vectors, $\Delta\overrightarrow{D}_i$, of the coordinates of each municipality on CCA axes $(x, y, \ldots n)$ from time t to time t + 1. The direction of $\Delta\overrightarrow{D}_i$ in relation to the reference CCA axis enabled us to determine the tendency of change of each municipality and its degree of social-ecological coupling.

$$\left\|\Delta\overrightarrow{D}_i\right\| = \sqrt{\left(x_{t+1_i} - x_{t_i}\right)^2 + \left(y_{t+1_i} - y_{t_i}\right)^2 + \ldots + \left(n_{t+1_i} - n_{t_i}\right)^2} \quad (1)$$

Student *t*-test was used to determine the statistical significance of the displacement intensities (i.e. the magnitude of social-ecological change of the municipalities), inside and outside PAs.

2.3.2. Quantifying changes in the hedgerow network inside and outside protected areas

The strategy of field data collection allowed us to assign to each municipality located inside and outside PAs boundaries, at the two different sampling times (2003 and 2013), the number, length, density and woody species richness of the hedgerow network. With the collected data, we calculated the variation rates of structural and biotic characteristics of the network. The statistical significances of the hedgerow descriptors inside-outside PA over time were tested by means of Student *t*-test.

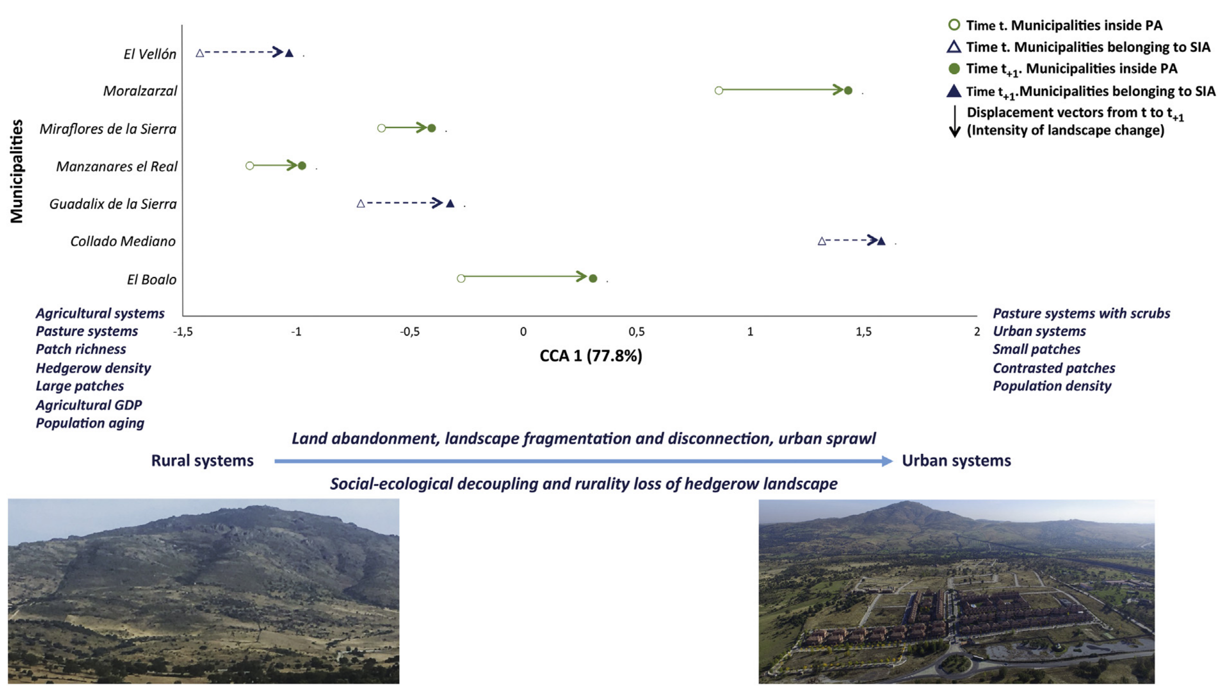

Fig. 2. CCA axis 1 showing the displacement over time of the municipalities that maintain the hedgerow landscape. Arrows show the direction and intensity (arrow length) of social-ecological change. Landscape and socioeconomic indicators of change (variables with higher scores in the CCA) are indicated at both ends of the axis (see Table 2). The change detected, both inside and outside protected areas (PAs and SIA, respectively), is interpreted as a process of social-ecological decoupling from rural systems to urban expansion. Pictures representing these two extreme situations are synchronous and distant from each other <500 m.

Table 2
a) Scores of the landscape descriptors (LULC and landscape metrics) along the first axis of the CCA. b) Scores of the socioeconomic variables along the first axis of the CCA.

a)

Landscape descriptors	CCA axis 1
Patch richness	−0.60
Agricultural systems	−0.46
Hedgerow density	−0.30
Largest patch index	−0.25
Pasture systems	−0.24
Mediterranean woodlands	−0.10
Euclidean nearest neighbour distance	−0.09
Coniferous formations	0.11
Urban areas	0.12
Edge contrast index	0.34
Splitting index	0.58
Pasture systems with scrubs	0.65

b)

Socioeconomic descriptors	CCA axis 1
Agricultural sector GDP	−0.73
Population aging	−0.24
Immigration	−0.02
Income per capita	0.01
Emigration	0.11
Population density	0.53

3. Results

3.1. Social-ecological dynamics of the hedgerow landscape

CCA results allowed us to identify the main trajectories of the social-ecological change of the hedgerow landscape throughout the study period, at municipal level. The first two CCA axes reveal the same social-ecological gradient. Since the variance explained by the first ordination axis is very high (77.8%), only the variation expressed by the CCA Axis 1 has been considered (Fig. 2). This axis is the product of the maximum possible correlation between landscape descriptors and socioeconomic variables.

We can observe that, in one decade, the hedgerow landscape has undergone a marked process of rurality loss linked to agricultural land abandonment, shrub encroachment, landscape fragmentation, hedgerow network degradation, landscape disconnection and urban sprawl, as indicated by the landscape descriptors with higher scores on CCA Axis 1 (Fig. 2; Table 2a). Thus, at the negative end of the axis, agricultural and pasture systems, patch richness, hedgerow density and large patches, are the main landscape indicators of traditional mixed rural systems based on agriculture, forestry and grazing, whereas that at the positive end of the axis, pasture systems with scrubs, urban areas and small and contrasted patches are the key indicators of the landscape change. This prevailing tendency of change, from left to right of Axis 1, highlights a process of rural social-ecological decoupling, with different societal and economic variables linked to the landscape gradient (Fig. 2; Table 2b): population aging and agricultural GDP in rural landscapes (negative end) and a relative high population density in the areas characterized by urban systems (positive end). The coordinates of the municipalities on the axis allow us to identify types of social-ecological systems with different degree of rural decoupling and, therefore, of rurality loss (i.e. degree of abandonment of traditional agrosilvopastoral uses and/or substitution by urbanized areas). These detected sets of municipality types have also dissimilar landscape patterns.

The arrows shown in Fig. 2 represent the direction and magnitude of the displacement vectors between the coordinates of the municipalities along Axis 1 from time t to t + 1. The analysis highlights that the rural decoupling process described has occurred in the seven municipalities that comprise the study area, regardless of their initial degree of rurality or location inside or outside PAs. The intensity (vector magnitude) of the social-ecological change, identified by the modules of the displacement vectors in Axis 1 (Fig. 2), is very similar inside and outside PAs (Table 3), and the values of the directional tendencies do not present statistically significant differences between PAs and SIA (Student's *t*-test $p = 0.35$).

3.2. Evolution of the wooded hedgerow network in a changing landscape context

Analysis of field data, based on the records of 109 hedges sampled twice over a decade, indicates that the hedgerow network has progressively been degraded and destructured, regardless whether it was inside or outside the limits of PAs. Indeed, the descriptors of the hedgerow network (number, length, density and woody species richness) have decreased their value over time and have had negative variation rates in all cases, both in PAs and SIA (Fig. 3; Table 3). Descriptors of the hedgerow network did not show statistically significant differences inside-outside PAs.

The decrease in woody species richness is associated with the decline and local extinction of species (Fig. 4). Thus, 48.72% of all species registered have declined their presence in the wooded network over the study period, while 17.95% of them have disappeared from the hedgerows studied in this time span. It is important to highlight that all the 39 species recorded are considered of multiple-use by the traditional ecological knowledge, providing multiple ecosystem services. Of the total woody species recorded in the hedges, 100% of them provide provisioning services, while 38.5 and 46.2% provide regulating and cultural services, respectively (Appendix A). The provisioning medicinal use is the most prominent. However, despite this, very few of these species have any category of protection according to different databases at international, Spanish or regional levels (Appendix A).

4. Discussion

Rural cultural landscapes with a long history of integrating forestry and agricultural activities have led to different types of land uses that have shaped complex landscape patterns with a high associated biocultural diversity (Agnoletti and Rotherham, 2015; Marull et al., 2015). Landscapes with hedgerow networks supply multiple ecosystem services in rural landscapes, playing an important role for biodiversity conservation, as they provide food resources for wildlife as well as nesting, breeding and hibernation sites. Furthermore, the abundance of flowers and fruits provides nectar for pollinating insects and supports

Table 3
Descriptors of the hedgerow landscape change over time. Displacement vector modules along CCA axis1 indicate the intensity of the social-ecological change occurred inside and outside PAs (see Fig. 2). Changes in structural and biotic features of the hedgerow network were quantified by means of the variation rates of the number, length, density and woody plant richness of the network (see Fig. 3). Calculations were performed at municipal scale.

Hedgerow landscape	Displacement vectors (mean vector modules)	Amount of Hedgerows (variation rate)	Hedgerow network length (variation rate)	Hedgerow network density (variation rate)	Woody species richness (variation rate)
Protected areas	0.40	−4.17	−13.45	−7.61	−9.68
Socioeconomic influence area	0.35	−8.20	−12.81	−13.16	−10.00

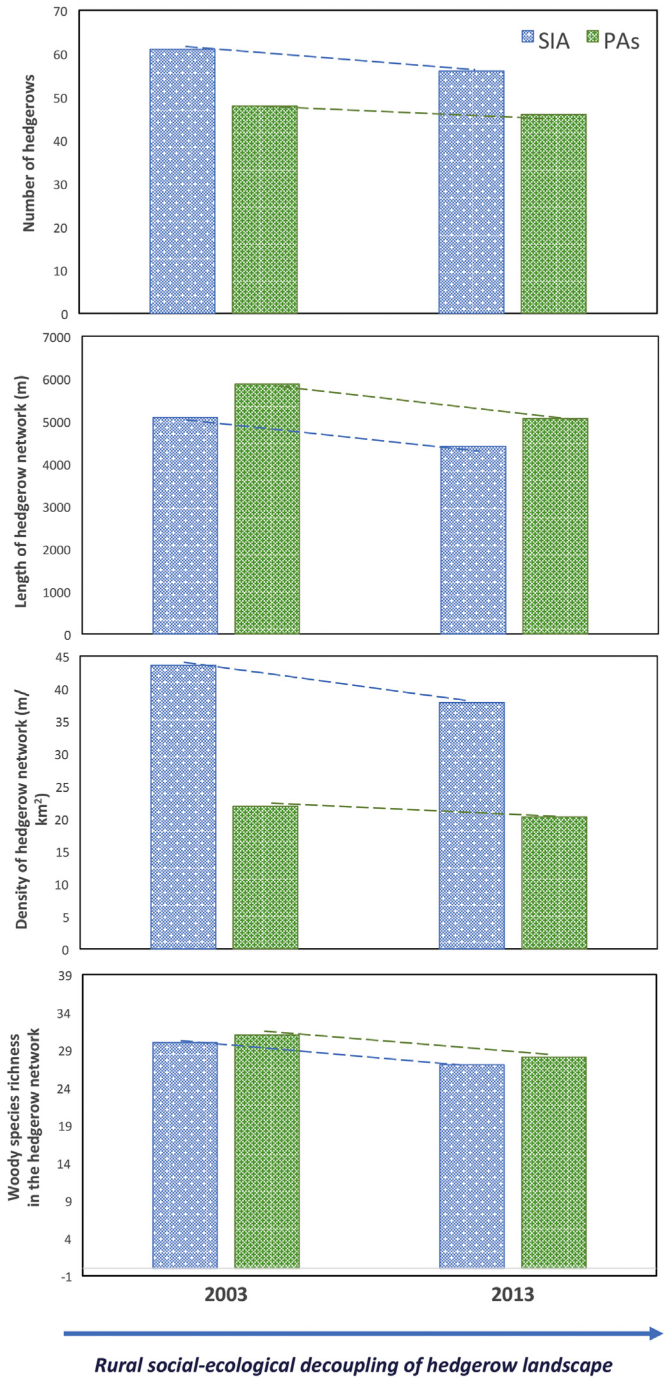

Fig. 3. Influence of the landscape context on the conservation of the hedgerow network studied. Variations over time of the characteristics of the hedgerow sampled (109 in 2003 and 102 in 2013), both inside and outside protected areas (PAs and SIA, respectively).

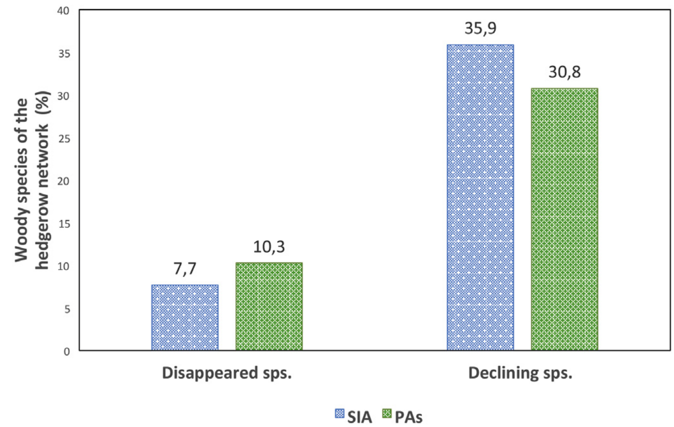

Fig. 4. Percentage of woody species that have disappeared or have declined their presence in the hedgerow network over the study period, both inside and outside protected areas (PAs and SIA, respectively).

a high level of fruit-eating fauna (Harvey, 2000; Oliveira et al., 2015; Hinsley and Bellamy, 2000; Staley et al., 2012). In these landscape types, ecological processes depend on the spatial structure of the network (Burel and Baudry, 1990). Several authors indicate that the preservation of connecting hedges or even their generation in suitable locations favours landscape connectivity (Burel and Baudry, 1995; Hanski et al., 2000; Wehling and Diekmann, 2009; Staley et al., 2012) and can reduce some detrimental effects of landscape fragmentation on the woodland fauna (Forman and Baudry, 1984; Hinsley and Bellamy, 2000; Davies and Pullin, 2007). Thus, many plant species typical of ancient stands as well as most woodland carabid species might be able to survive in relict hedgerows (Wehling and Diekmann, 2009), which, like ancient woodland, can be a valuable source for recolonisation processes and persistence of many typical woodland species (Buse, 2012).

The used method is a productive analytical tool addressed to identify the degree of interdependency and coupling between two systems (Parcerisas et al., 2012; Gatzweiler, 2014). Its application has allowed us to characterise the changing relationships between landscape and socioeconomic structures and the degree of social-ecological coupling of the hedgerow landscape studied. Also, this methodological approach detects different states of the system, quantifying the intensity of changes due to environmental and management shifts (Barros et al., 2016). The limitations of the method are those inherent to the availability of landscape descriptors and socioeconomic databases.

In the study area, as in other traditional Mediterranean agricultural areas, the main tendencies of change experienced by the hedgerow cultural landscape are processes such as the progressive advance of land abandonment with a sharp reduction of farms, crop fields and pastures, shrub encroachment with patches of scrub becoming ever larger, landscape fragmentation and disruption of ecological connectivity by human-induced disconnection between habitats, urban expansion and rurality loss (Millington et al., 2007; Petanidou et al., 2008; Schmitz et al., 2012). Changing social-ecological relationships from rural to urban systems cause rural decoupling and its corresponding environmental consequences. The analysis performed has allowed detecting types of social-ecological systems with different degree of rural decoupling and dissimilar landscape patterns. Urban expansion implies the transformation of rural and natural landscapes into urban systems, modifying complex social-ecological relationships through demographic and economic changes (Antrop, 2004; Seto et al., 2010). This generates alterations in ecological functions and processes that depend on the flow of energy and material through the landscape (Ribeiro Palacios et al., 2013; Arnaiz-Schmitz et al., 2018) and threats the sustainability of ecosystem services (Lindenmayer and Fischer, 2013). These processes are linked to a noteworthy hedgerow degradation (Fig. 2).

The medieval hedgerow landscape of Central Spain is an old and singular culture-based system characteristic of mountainous areas (Schmitz et al., 2007; Sánchez and McCollin, 2015; Schmitz et al., 2017), and several authors have highlighted their importance and uniqueness (Bernáldez, 1991; Franco-Múgica et al., 1998; Schmitz et al., 2017). Despite the establishment in the study area of several PA categories with management plans aimed at improving, recovering and implementing traditional agrosilvopastoral activities as a means of protection and conservation of rural systems (Madrid Regional Government, 1992; BOE, 2013), the ancient hedgerow network of the study area is nowadays subjected to a pronounced intensity of change. Thus, this landscape, which in the past was mainly composed of pastures and dehesas surrounded by a well-developed and connected hedgerow network, is at present in a high degree of neglect and downgrade, which includes the abandonment or removal of hedges (Schmitz et al., 2017) and is only represented in a few municipalities that have scarce hedgerows in an acceptable state of conservation for their study, sampling and monitoring (Fig. 1). Our own field data, based on monitoring 109 hedges through time, confirm this process. The woody network has progressively been destructured and disconnected and all the descriptors of the status conservation of the hedgerow landscape have diminished their value in time, presenting negative rates of variation, both inside and outside PAs (Fig. 3; Table 3).

Worldwide, hedgerow statistics show net changes mainly in the length of hedges, with losses of up to 71% since 1950 in the American Midwest, Eastern Europe and the UK (Dover and Sparks, 2000; Sklenicka et al., 2017; Boughey et al., 2011). These losses are largely associated with deficiencies of management (Carey et al., 2008). We observed the same tendency in our study, where the length of the hedgerow network presents high rates of variation over time (−13.45 and −12.81 inside and outside PAs, respectively, Table 3). The maintenance of hedgerow length is a good descriptor of the state of conservation of the rural landscape and its functionality (Scozzafava and de Sanctis, 2006). Hedgerow length is a measure of the available habitat, and its diminution implies the reduction of landscape connectivity, decreasing the probability of movement of individuals between habitat patches (Hanski et al., 2000) and, therefore, the landscape ability to provide food and shelter to wildlife (Bright and MacPherson, 2002). In general in the study area, as indicated by the descriptors used, most of the remaining hedgerows are in poor condition and also threatened by a lack of appropriate management. Therefore, hedgerows, a key landscape feature for the provision of ecosystem services and habitat for wildlife, have been degraded through neglect, which is probably the major cause of recent loss of hedgerows in Europe (La Trobe and Acott, 2000).

Landscapes rich in biocultural diversity with a high conservation value are often managed at small-scale by peasant farmers, pastoralists and traditional livestock keepers (Agnoletti and Rotherham, 2015). The persistence of these rural landscapes depends on the maintenance of the traditional land uses and management of local population (Brosi et al., 2007) and their conservation requires societal recognition, research and protection policies. Management plans aiming at conserving these multifunctional cultural landscapes, must therefore be based on social-ecological relationships and fluxes of ecosystem services. Conservation of landscape-ecological structures such as the hedgerow network under study also means preserving their role in maintaining landscape connectivity, avoiding habitat fragmentation and protecting local biodiversity that provide useful services to the human society.

Results of this study highlight the significance of traditional knowledge on landscape conservation and management and its implications for the conservation of biocultural diversity (Berkes and Davidson-Hunt, 2006). The described degradation process is associated with the decline and even the local extinction of woody species in the hedgerow network studied (Fig. 4). Most of these species have several traditional uses such as medicinal, fuel, sources of material, animal or human feeding, sources of nectar and pollen, ornamental or symbolic uses, providing different ecosystem services (Appendix A). In spite of their known ecological and cultural value, very few of them are recognized with some category of protection in advisory lists for species conservation and even in these cases their conservation category has not prevented their decline or loss (e.g. *Malus sylvestris* is considered as "Special Interest" by the Regional Catalogue of Threatened Species of the Community of Madrid, but this species is declining inside PA and missing in SIA; Appendix A). This seems to reveal inconsistencies or weaknesses in the management of the study area that can be interpreted from the perspective of the management effectiveness of current PAs in meeting certain conservation targets and to achieve a protection effect (Hannah et al., 2007; Schmitz et al., 2012, 2017).

The future of hedgerow landscapes depends on the dynamics of the rural society, nowadays tending towards the decline of traditional activities and to a new non-farm rural economy (Burel, 1996; Schmitz et al., 2012). Several European countries include hedgerow management in their Agri-Environment Schemes (Baudry et al., 2000; Fuentes-Montemayor et al., 2011) recognising the ecological importance and vulnerable conservation status of hedgerows and providing incentive mechanisms for hedgerow conservation (Barr and Gillespie, 2000; Kleijn and Sutherland, 2003; Schleyer and Plieninger, 2011; Sklenicka et al., 2017), because a good hedgerow management has costs and its application is unlikely in the absence of policies that contemplate its conservation and of available funds for this purpose (Hinsley and Bellamy, 2000). Thus, farmers are paid with public subsidies to manage hedgerow networks and benefit wildlife (Boughey et al., 2011). In spite of their recognized social-ecological importance, hedgerow landscapes are not mentioned in the management plans of Central Spain PAs and are barely mentioned in other Spanish nature reserves. Government policies have neither valued the historical and ecological importance of this species-rich hedge network and its current vulnerability (Appendix A). This implies significant biological and cultural losses and shows certain ineffectiveness in the management of protected cultural landscapes, since learning from traditional management systems is important to extent conservation objectives and approaches (Berkes and Davidson-Hunt, 2006). Moreover, the fact that most management plans are constrained by administrative boundaries instead of being based on social-ecological relationships and fluxes of ecosystem services, accentuates their ineffectiveness when aiming to protect an inter-municipal hedgerow landscape (Martín-López et al., 2011).

5. Conclusion

In this paper, we analyse a relict hedgerow landscape in Central Spain, once well-developed and conspicuous, which is being degraded at alarming rates due to socioeconomic changes linked to rural social-ecological decoupling, land protection and abandonment. This process is related to the loss of woody species of traditional use and conservation interest and other ecosystem services provided by hedgerows. The establishment of PAs does not mitigate the degradation of the hedgerow landscape.

The results obtained stand out the importance of traditional knowledge and management practices developed over the centuries by local population. Decision-makers should take them into account because their recognition, enhancement and application is a way to constitute a robust, inclusive and effective tool for the management and conservation of rural cultural landscapes, especially those designated under different categories of protection for their high cultural and natural values.

We state the need to elaborate regulations and tools for the protection of hedgerow landscapes in the Spanish legislation, based on social ecological interactions, at least in the Master Plans for Use and Management of the PAs, so that they can be more effective in conserving the heritage of cultural landscapes and their valuable biocultural diversity.

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Appendix A

Woody species sampled in the hedgerow network. We indicate for each species: main traditional use, ecosystem service provided, status of conservation over the study period inside and outside protected areas (PAs and SIA, respectively) and the category of protection according to protected and threatened species databases at international (IUCN, 2017), Spanish (Moreno, 2008; Bañares et al., 2010) and regional (Madrid Regional Government, 1992) levels.
Traditional use codes: AF; Animal feeding; CO, Wood used for rural constructions (houses, stables, fences and gateways); FW, Fire wood; HF, Human feeding; HO, Honey plant; MA, Raw material for manufactured products (furniture, tools and rural utensils, textile uses); ME, Medicinal uses (human and/or veterinary medicine); OR, Ornamental plants; SR, Symbolic, ritual or ceremonial use.
Ecosystem services categories: P, provisioning; R, regulating; C, cultural. Classified according to the Millennium Ecosystem Assessment (2005).
Conservation status codes: I, increasing; D, declining; NP, not present; R, remaining; E, extinct.
Protection and threat use codes: NE, Not evaluated; DD, Data deficient; LC, Least concern; NT, Near threatened; VU, Vulnerable; CR, Critically endangered; NOP, Non protected; SE, Special interest.

Species	Traditional uses	Ecosystem Services	Conservation status in the hedgerow network		Protection and threat categories		
			PAs	SIA	IUCN	Spain	Madrid Region
Acer monspessulanum	CO/MA	P	I	R	NE	NE	NOP
Bryonia dioica	HO/ME	P/R	D	D	NE	NE	NOP
Crataegus monogyna	AF/HF/HO/ME	P/R	D	I	NE	NE	NOP
Cytisus scoparius	HO/ME	P/R	D	D	NE	NE	NOP
Daphne gnidium	MA/ME/SR	P/C	D	R	NE	NE	NOP
Euonymus europaeus	MA/ME/OR	P/C	I	R	NE	CR	NOP
Ficus carica	AF/HF/ME	P	NP	D	LC	NE	NOP
Fraxinus angustifolia	AH/MA/ME	P	D	R	NE	NE	NOP
Hedera helix	HO/ME	P/R	E	NP	NE	NE	NOP
Jasminum fruticans	ME/OR	P/C	NP	D	NE	NE	NOP
Juglans regia	CO/HF/MA/ME	P	E	D	NT	NE	NOP
Juniperus oxycedrus	MA/ME/OR	P/C	R	R	LC	VU	NOP
Ligustrum vulgare	MA/ME/OR	P/C	R	R	NE	NE	NOP
Lonicera etrusca	HO/MA/ME/OR	P/R/C	D	E	NE	NE	NOP
Lonicera periclymenum	HO/MA/ME	P/R	NP	I	NE	NE	NOP
Malus sylvestris	AF/HF/HO/ME	P/R	D	E	DD	NE	SE
Olea europaea	HF/ME	P	NP	D	NE	NE	NOP
Osyris alba	AF/ME	P	NP	R	NE	NE	NOP
Populus alba	MA/ME/SR/OR	P/C	R	NP	NE	NE	NOP
Populus nigra	AF/CO/MA/ME/OR	P/C	D	NP	LC	NE	NOP
Prunus domestica	HF/HO/MA/ME	P/R	I	R	NE	NE	NOP
Prunus dulcis	AF/HF/HO/MA/ME/OR	P/R/C	NP	D	NE	NE	NOP
Prunus persica	HF/HO/ME	P/R	E	NP	DD	NE	NOP
Prunus spinosa	AF/HF/HO/MA/ME	P/R	D	I	LC	NE	NOP
Quercus faginea	AF/CO/FW/MA/SR	P/C	R	I	NE	NE	NOP
Quercus ilex	AF/FW/MA/SR	P/C	I	D	NE	NE	NOP
Quercus pyrenaica	AF/CO/FW/MA/SR	P/C	D	D	NE	NE	NOP
Rhamnus cathartica	ME	P	I	I	NE	NE	NOP
Robinia pseudacacia	HO/MA/ME/OR	P/R/C	R	NP	NE	NE	NOP
Rosa canina	AF/HF/HO/ME	P/R	D	D	NE	NE	NOP
Rubus ulmifolius	AF/HF/FW/HO/MA/SR	P/R/C	I	D	NE	NE	NOP
Ruscus aculeatus	MA/SR	P/C	NP	E	NE	NE	NOP
Salix atrocinerea	HO/MA/ME	P/R	R	NP	NE	NE	NOP
Salix purpurea	MA/ME/SR	P/C	R	NP	LC	NE	NOP
Salix salvifolia	MA/ME	P	R	R	NE	NE	NOP
Santolina rosmarinifolia	ME	P	R	NP	LC	NE	NOP
Tamus communis	ME	P	R	D	NE	NE	NOP
Ulmus minor	AF/MA/ME/SR	P/C	D	D	NE	NE	NOP
Ulmus pumila	AF/MA/ME/OR	P/C	E	NP	NE	NE	NOP

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ARTÍCULO 08

Título: Rural tourism: crossroads between nature, socio-ecological decoupling and urban sprawl.

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Resumen:
El desarrollo del turismo cultural ha convertido los paisajes rurales tradicionales, caracterizados por sus grandes valores naturales y culturales, en el foco de la atracción turística, causando cambios importantes en la estructura socioeconómica de las regiones en las que se encuentran. El aumento de este turismo destaca la necesidad de diseñar e implementar una gestión sostenible que garantice el mantenimiento y la conservación del paisaje y el desarrollo económico de las poblaciones locales. Este estudio, localizado en el Valle de Lozoya (Sierra de Guadarrama, Centro de España), analiza la situación socio-ecológica de sus municipios y visitantes en dos momentos diferentes. El análisis de la evolución temporal ha permitido advertir un marcado desacoplamiento socio-ecológico caracterizado por la expansión urbana, la pérdida de los usos y las prácticas tradicionales y la ruralidad de la sociedad local. Al mismo tiempo, se detecta una disminución en la valoración del paisaje rural por parte de los visitantes, aumentando sus preferencias por la naturalidad. El estudio realizado es una contribución novedosa aplicable a la gestión para la conservación del paisaje y al desarrollo del turismo sostenible para la naturaleza y la sociedad.

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RURAL TOURISM: CROSSROADS BETWEEN NATURE, SOCIO-ECOLOGICAL DECOUPLING AND URBAN SPRAWL

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ABSTRACT

The development of cultural tourism has turned traditional rural landscapes, characterized by their great natural and cultural values, into focus of tourism attraction, causing important changes in the socio-economic structure of the regions containing them. The enhancement of this tourism highlights the need to design and implement a sustainable management that guarantees the maintenance and conservation of the landscape and the economic development of local populations. This study, localised in the Lozoya Valley (Guadarrama Mountains, Central Spain), analyses the socio-ecological situation of its municipalities and visitors in two different times. The analysis of its temporal evolution has allowed us to notice a marked socio-ecological decoupling characterized by urban sprawl, loss of traditional land-uses and practices and the rurality of local society. At the same time, a decrease is detected in the rural landscape valuation by visitors, increasing their preferences for naturalness. The conducted study is a novel contribution applicable to the conservative management of the landscape and the development of sustainable tourism for nature and society.

Keywords: conservative management, landscape dynamics, local socio-economy, multivariate analysis, rural tourism, sustainable tourism, typology of visitors.

1 INTRODUCTION

Cultural landscapes are conceived as 'social-ecological systems' [1] that represent a complex network of relations between nature and culture, biological and cultural diversity, tangible and intangible heritage and human identity [2]. Socio-ecological interactions convert cultural landscapes into dynamic systems in which their natural and socio-economic components co-evolve [3], [4].

Degradation of the rural cultural landscape impacts on natural systems affecting their ability to supply the demand for ecosystem services on which human activities are based [5]–[7]. This problem has acquired great relevance in Mediterranean rural landscapes. Land uses and ecosystem services, associated with their millenarian landscapes, have been drastically modified, subjected to intense anthropogenic pressures linked to new socio-economic processes [8], [9]. Among them is the process of rural abandonment, which has favoured the loss of many of the traditional activities that have allowed the maintenance of historical cultural landscapes for centuries [10]–[12]. This has important ecological consequences such as biodiversity loss, increase of fire frequency and intensity, soil erosion and desertification, reduction of landscape diversity, reduction of water provision and loss of cultural and aesthetic values [13], [14].

The European Landscape Convention [15] defines the idea of landscape in this way: "an area perceived by people, whose character is the result of the action and interaction of natural and/or human factors". The perceptive nature of the landscape [16] and its dependence on the natural environment and cultural processes [17] has already been recognized. A landscape can be valued based on the subjective appreciation of its physical, biological and cultural

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components by human society. The development of cultural tourism has turned traditional rural landscapes, characterized by their great natural and cultural values, into focus of tourism attraction, causing important changes in the socio-economic structure of the regions containing them. Knowing the perception of the visitors of an area is a first step to land planning, management plans and decision-making that allow a sustainable, culturally equitable and economically profitable tourism development [18], [19].

The aim of this work is to determine both the socio-ecological dynamic experienced by a traditional rural landscape recognized as high tourist value and the change of the landscape valuation by visitors. In order to achieve this, the following specific objectives were addressed: i) Detect the variation in time of the coupling or linkage between the characteristics of the rural landscape and the socioeconomic structure of the local population, identifying the main social-ecological indicators of the linkage over a period of two decades; ii) in this landscape context, analyse the typology of visitors to the study area, their perception and preferences and the significant change in their landscape valuation according to the socio-ecological dynamics of the study area.

2 METHOD

2.1 Study area

The study area focuses on the Lozoya Valley, a mountain valley located in the northern Sierra de Guadarrama, in the Lozoya river basin (Madrid region, Spain) and includes 30 municipalities. Its altitude ranges from 1,100 to 2,400 m asl. The vegetation is characterized by Pyrenean oak (*Quercus pyrenaica*) and Scots pine (*Pinus sylvestris*) forests, Mediterranean shrublands and upland grasslands. In the lower areas, traditional silvo-pastoral systems (*Q. pyrenaica* forestry-grazing) appear, with a heterogeneous mosaic of traditional land uses containing pastures, meadows, hedgerows, ash groves and riparian forests, all of which are well preserved in most cases.

The landscape structure of the area has been the result of ancient land use systems and rural activities that for centuries have been performed in the region contributing to their great socio-ecological value [20], which have made them worthy of different categories of protection. Thus, the Lozoya valley is within the boundaries of the Sierra de Guadarrama National Park (established in 2013) and the Sierra del Rincón Biosphere Reserve (2005). It belongs to the European network of protected sites Natura 2000 (Habitat Directive and Birds Directive), comprising an area classified as Site of Community Importance (SCI) and for Special Areas of Conservation (SAC) (Cuenca del río Lozoya y Sierra Norte) and a Special Area of Conservation for Birds (SPA) (High Valley of the Lozoya River).

Regarding the recognition of other categories of natural and cultural heritage, there are also several notable areas inside the valley as: i) Montejo de la Sierra beech forest, the most southern beech forest in Europe, declared as Natural Site of National Interest (by the Government of Spain in 1974) and World Heritage Site (by UNESCO, 2017); ii) Monastery El Paular, declared as Historical-Artistic Monument of Spain (by the Government of Spain, 1876); iii) the Neanderthals Valley, an upper Pleistocene archaeological site declared as Cultural Interest Good (by the Government of Spain, 2004); and iv) a proposed Geosite with International Significance (by the Geological and Mining Institute of Spain). Moreover, the High Valley of the Lozoya River has been proposed as a model of Heritage Cultural Landscape to UNESCO by the Spanish National Plan of Cultural Landscape (2012). Thus, the area is very appreciated by visitors to the Madrid region [21].

2.2 Socio-ecological analysis

We collected socio-ecological information from the valley using two types of descriptors: i) quantitative data of land use and land cover (LULC), recorded in 1989 and two decades later, 2010 [22]; and ii) socio-economic data of the local population at equivalent times (1990 and 2011) [23]. We consider the 30 municipalities of the valley as units of analysis because they constitute the smallest unit of governance and management in the Madrid region and also the most detailed level at which LULC and socio-economic census data are available [24], [25]. The data matrices analysed, ($m \times d_L$) and ($m \times d_S$), contained the set of municipalities described over time by means of 46 LULC and 27 socioeconomic descriptors, respectively. In order to quantify the relationship between LULC and socio-economic structures in time, we performed a Canonical Correspondence Analysis (CCA) to know the main links between both sets of descriptors [26], [27]. The CCA allows us to know the tendency and magnitude of the socio-ecological changes that occurred in each of them in the period of time elapsed.

2.3 Classification of the visitors

The landscape valuation of the Lozoya Valley by the visitors was examined through surveys carried out in two years (2007 and 2017). Questionnaires to visitors were conducted during weekends and vacation periods, from autumn to summer. The interviewed visitors were chosen randomly in the valley and their access routes in areas considered to be of particular interest for recreation and tourism. No more than two people were surveyed within each group of visitors. The questions did not refer only to those places, but rather to landscape characteristics of the whole valley. Visitors were asked about four classes of questions: i) sociological profile; ii) reasons for visiting the area; iii) landscape typology preferences; and iv) profile of intended activities.

The sampling work field implied 100 questionnaires per each year sampled. Two matrices of qualitative data, one for each year, t_1 and t_2, with 46 variables corresponding to the landscape preferences of the interviewees (iii-type) were set up. Types of visitors were obtained analysing the two matrices, t_1 and t_2, independently by means of a multivariate analysis of classification non-hierarchical K-means, using Wilks' lambda as optimization criterion. Groupings of visitors obtained were validated through Discriminant Analyses, applying the Rao's approximation.

Variables corresponding to questions (i), (ii) and (iv) were considered as external descriptors of each of the visitor types and tested by means of a χ^2 analysis.

3 RESULTS

3.1 Socio-ecological dynamics

The first CCA axis shows the main change tendency of the rural landscape (29.90% variance accounted for). Avoiding redundant results (axes 1 and 2 explain landscape variability in a very similar way), we focus only on the first axis, which describes the change of landscape during two decades and shows a gradient of socio-ecological decoupling and loss of rurality (Fig. 1). At the negative end, according to the loadings of the LULC descriptors, d_L, the axis highlights silvo-pastoral systems and, according to socio-economic descriptors, d_S, a rural society mainly dedicated to livestock farming. The positive end, on the contrary, is characterized by a noticeable shrub encroachment process linked to the abandonment of rural activities and urban sprawl, as well as to a high rent per capita of the local people (Fig. 1).

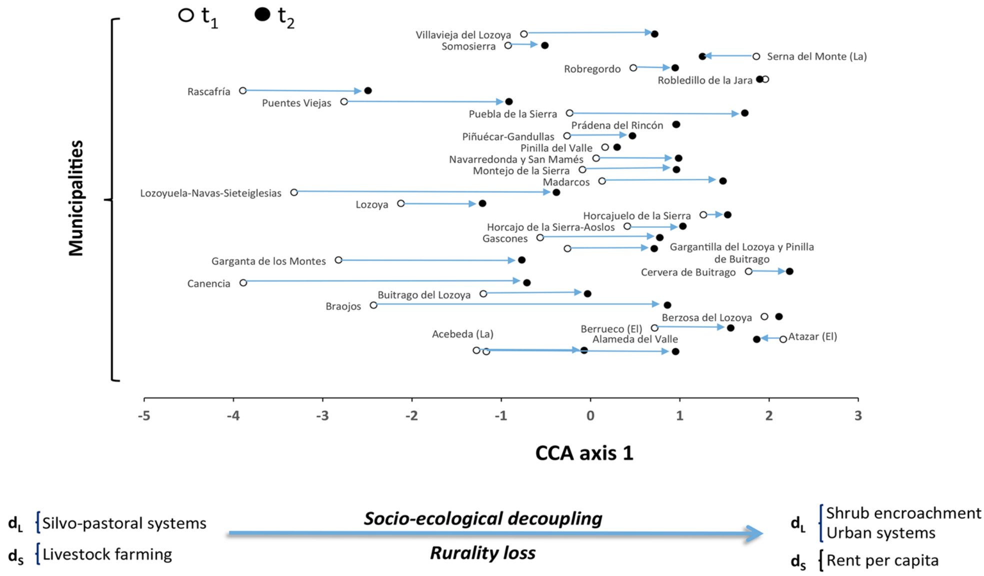

Figure 1: Position of the municipalities of the Lozoya Valley along the main axis of a CCA. Above, the vertical distribution of the municipalities only corresponds to an alphabetical order). The analysis was performed simultaneously on two data matrices (municipalities x LULC descriptors), d_L, and (municipalities x socioeconomic descriptors), d_S. The five descriptors of higher loadings are displayed at the bottom of the figure. The coordinates of the municipalities on the CCA axis 1 are linked by arrows showing the direction and magnitude of the socio-ecological change from t_1 (LULC data of 1989 and socioeconomic data of 1990) to t_2 (2010 and 2011, respectively).

Along the CCA axis 1, we have drawn arrows joining the coordinates of the municipalities from t_1 to t_2. This has allowed us to know the direction and intensity of the socio-ecological change (the study period). The magnitude of the change has been great in municipalities such as Lozoyuela, Canencia or Braojos and little important in Robregordo, Horcajuelo de la Sierra or El Atazar, which remain almost unchanged over time.

3.2 Characterization of visitors

3.2.1 Typology of visitors in 2007

Four types of visitors were obtained: i) Natur-generalist visitors – 'Ecogeneralists' – (26%), value any type of landscape with natural elements. They are people of mature age without special incentives to visit the area, although have a certain preference for activities related to nature, such as watching birds, other animals, vegetation, nature photography, ...; ii) Rural-naturalist visitors (25%), show preference for natural and rural-cultural landscapes. They are young people (16–24) who visit these places for their rural landscape, for sport or simply enjoy nature or have a picnic; iii) Family tourism visitors (21%), attracted by both natural as cultural values, especially water landscapes; and iv) Indifferent visitors (28%), with little motivation to visit the valley – a sociologically heterogeneous group, without concrete preferences for any landscape type or landscape component.

Table 1(a) shows the two first discriminant functions indicating the degree of preference, indifference or rejection of a set of variables that represent characteristics of the landscape in 2007. The first discriminant function, F1, allowed us to detect on this date, by means of four landscape indicators (higher discriminant loadings), a gradient of visitor preferences for natural and rural characteristics of the landscape (Fig. 2(a)). Ecogeneralist (i) and Rural-Naturalist (ii) visitors are those that show a greater appreciation for these aspects of the landscape.

3.2.2 Typology of visitors in 2017

One decade later, the analysis of the Lozoya valley visitors again detected four types, but some of their characteristics have clearly changed: i) Sports-generalist visitors (32%) with a wide range of landscape preferences. This is a group formed only by women who play sports; ii) Naturalist visitors (31%) show a clear preference for the naturalness of the landscape against its rurality. Members of this group are young people who practice cultural activities, nature photography, animal watching, picnics in nature, …; iii) Family tourism visitors (21%) value cultural and natural aspects of the territory. Their landscape preferences are related to vegetation and aquatic elements; and iv) Mountainous landscape visitors (16%) prefer high-altitude landforms, water systems and cultural elements of landscape. They practice hiking and enjoy naturalness. Components of this group belong to a wide range of ages and have in common the city of Madrid as origin.

Table 1: Indicators of the landscape preferences of visitors in both times studied (2007 and 2017). They were obtained through Discriminant Analyses considering the valuations of landscape features. Loadings in F1 and F2 are indicated. 1 and 0 represent, respectively, preference (1) and rejection or indifference (0) in the valuation of the landscape variables.

(a) 2007			
Variables	F1	Variables	F2
Juniper groves-1	-0.83	Agricultural land mosaics-1	-0.42
Shrublands-1	-0.82	Rainfed crops-1	-0.41
Poplar and birch groves-1	-0.81	Irrigated crops-1	-0.37
Agricultural land mosaics-1	-0.81	Irrigated crops-0	0.37
Agricultural land mosaics-0	0.81	Rainfed crops-0	0.41
Poplar and birch groves-0	0.82	Agricultural land mosaics-0	0.42
Shurblands-0	0.82		
Juniper groves-0	0.83		
(b) 2017			
Variables	F1	Variables	F2
Ash tree forests-0	-0.80	Rainfed crops-1	-0.70
Pyrennean oak forests-0	-0.78	Agricultural land mosaics-1	-0.65
Holm oak forests-0	-0.76	Olive groves-1	-0.63
Holm oak forests-1	0.76	Olive groves-0	0.63
Pyrennean oak forests-1	0.79	Agricultural land mosaics-0	0.65
Ash tree forests-1	0.80	Rainfed crops-0	0.70

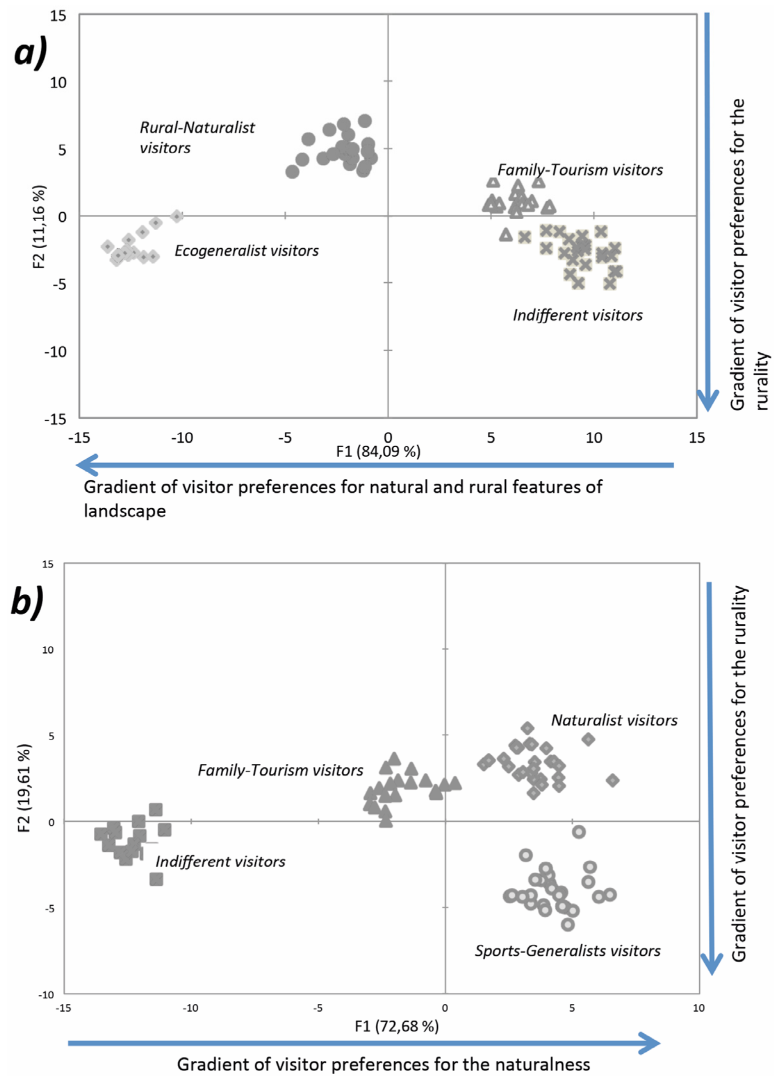

Figure 2: Discriminant analysis of the types of visitors to the Lozoya Valley. The two main landscape valuation tendencies are highlighted (obtained from the first two discriminant functions). a) 2007; b) 2017. See Table 1.

In Table 1(b), the variables with higher loadings in the discriminant function F1 are three landscape descriptors representing arboreal formations with a high degree of naturalness. In F2 also three variables are, in this case, indicators of the agricultural rural landscapes. The preferences of these landscape indicators segregate the types of visitors in the plane defined by the first two discriminant functions. F1 shows a gradient of preferences of visitors for naturalness and F2 shows a gradient of preferences for rurality (Fig. 2(b)).

4 DISCUSSION

The ancient multifunctional landscape of the Lozoya Valley is characterized by a heterogeneous mosaic of traditional land use systems. This landscape has been generated through a complex network of biophysical and cultural processes which have resulted in a valuable heritage landscape [8], [16], [28]. Although conservation efforts to preserving this heritage landscape had been made at national and international level, management plans do not seem to have been adequate for the conservation objectives, putting at risk their continuity. Thus, the study of this landscape over time highlights an intense change both in land-use composition and socio-economy of the local population and, therefore, in the structure and functioning of the rural system.

The tendency of change varies from the traditional agrosilvopastoral system and livestock farming to shrub encroachment linked to the rural abandonment and urban sprawl. This has brought along a remarkable process of socio-ecological decoupling and loss of rurality in most of the municipalities of the valley.

In any case, the landscape is attractive for cultural tourism, their valuation by the visitors has changed over the period studied, although the tourist stereotypes have been maintained, finding both generalist and specialized visitors [24], [29]–[31]. In the first year studied, the types of visitors mainly differed from each other along a gradient of rural landscape assessment, expressed by the calculated first discriminant function (84.09% explained variance). The preference for naturalness, summarized by the second discriminant function, is significantly lower (11.16%). A decade later, an exchange of the landscape interests of the visitors is detected, acquiring a greater importance the naturalness (72.68% variance absorption; first discriminant function) in front of the rurality (19.61%; second function; Fig. 2(a), (b)).

5 CONCLUSION

The integrated study of the dynamics of the landscape structure of the Lozoya Valley and the socio-economy of its local population has allowed us to detect a clear tendency towards a socio-ecological decoupling characterized by the urban sprawl and the loss of both traditional land-use practices and rurality of the society.

Linked to a process of rural socio-ecological decoupling there are both a decrease in the valuation of the rural landscape by visitors and an increase in their preferences for naturalness. This indicates a certain ineffectiveness in the management of a heritage cultural landscape which includes categories of protection institutionally recognized as “of high ecological, natural and cultural value”.

Results clearly show the need for this type of studies to manage and promote a cultural-natural tourism based on the maintenance of those traditional rural activities that generated this heritage cultural landscape, prioritizing its conservation, the nature protection and the economic development of local population.

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